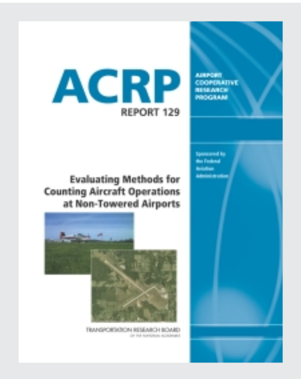

Evaluating Methods for Counting Aircraft Operations at Non-Towered Airports

DETAILS

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AUTHORS

Maria J. Muia and Mary E. Johnson; Airport Cooperative Research Program; Transportation Research Board; National Academies of Sciences, Engineering, and Medicine

AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP REPORT 129

Evaluating Methods for Counting Aircraft Operations at Non-Towered Airports

Maria J. Muia
WOOLPERT, INC.
Indianapolis, IN

Mary E. Johnson
PURDUE UNIVERSITY
West Lafayette, IN

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

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The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

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Michael R. Salamone, *ACRP Manager*
Joseph D. Navarrete, *Senior Program Officer*
Terri Baker, *Senior Program Assistant*
Eileen P. Delaney, *Director of Publications*
Margaret B. Hagood, *Editor*

ACRP PROJECT 03-27 PANEL
Field of Policy and Planning

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Kerry L. Ahearn, *Boulder City Airport, Boulder City, NV*
John J. Barker, *City of Lee's Summit Missouri, Lee's Summit, MO*
Peter D. Buchen, *Minnesota DOT, Roseville, MN*
Richard Lanman, *Auburn-Lewiston Airport, Auburn, ME*
Kay A. Thede, *Clapsaddle-Garber Associates, Inc., Ames, IA*
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Richard A. Cunard, *TRB Liaison*

AUTHOR ACKNOWLEDGMENTS

The ACRP Project 03-27 research team was led by Woolpert, Inc. Subconsultants on this project were Purdue University's Aviation Technology Department and Hybrid-3, Inc. Maria J. Muia, Ph.D., senior aviation planner for Woolpert, Inc., was the project director and principal investigator. Mary E. Johnson, Ph.D., professor for Purdue University, was the authority on the statistical analysis. The aforementioned were contributing authors of the final report.

Other individuals who contributed to the project through field testing, statistical analysis, surveying, and literature review were (listing here does not imply authorship of this document): Ryan McCroskey and Brad Cozza of Woolpert, Inc.; Joyce Brummett, Hybrid-3, Inc.; Anthony Erstad, Brian Dillman, Stewart W. Schreckengast, Jennifer Kirschner, Steven M. Leib, Scott R. Winter, Yue Liu, Denver Lopp, and Chien-tsung Lu of Purdue University; and Marcus Dial, Indiana Department of Transportation.

The research team would like to thank the following airports for participating in this study: Indianapolis Executive Airport (TYQ); Purdue University Airport (LAF); Eagle Creek Airpark (EYE); and Paoli Municipal Airport (I42).

FOREWORD

By Joseph D. Navarrete
Staff Officer
Transportation Research Board

ACRP Report 129: Evaluating Methods for Counting Aircraft Operations at Non-Towered Airports provides a thorough review of techniques and technologies for estimating aircraft operations at airports without air traffic control towers. The report documents the industry's first comprehensive evaluation of the most common traffic estimation methods and is especially valuable to practitioners seeking to develop a statistically defensible estimate of aircraft activity for their non-towered airport.

Aircraft operations counts are used as input for determining funding and design criteria at the nation's airports. They are also needed for developing the forecasts used to prepare airport master plans, aviation system plans, and environmental studies. Yet most airports don't have accurate activity records because they do not have an air traffic control tower, or because the tower does not operate 24 hours per day. Various techniques have therefore been used to obtain activity estimates at these facilities, including generic operations-per-based-aircraft ratios, guest logs, fuel sales, visual observation, automatic counters, acoustical counters, and video data capturing devices. However, no systematic review of these techniques has been undertaken. Research was needed to evaluate aircraft operations-counting estimation techniques and technologies and to develop guidance to assist airport practitioners in selecting and using the most appropriate methods given available resources, accuracy requirements, and airport layout.

The research, led by Woolpert, Inc., built on the results of *ACRP Synthesis 4: Counting Aircraft Operations at Non-Towered Airports* by reviewing recent literature and identifying new technologies. The research team then reached out to stakeholders to identify how operations data are used, confirm the criteria practitioners consider when selecting a counting method, and determine the most common counting methods used by the industry. Next, a testing program was conducted to evaluate the accuracy of three methods, including:

- Multiplying based aircraft by an estimated number of operations per based aircraft,
- Applying a ratio of FAA flight plans to total operations, and
- Expanding a sample count into an annual estimate through extrapolation.

For the sampling method, the testing program also looked at the accuracy of different aircraft traffic counting technologies, including:

- Automated acoustical counter,
- Sound-level meter,
- Security/trail cameras, and
- Video image detection with a transponder receiver.

The testing program involved installing counting systems at four airports for extended time periods to test their accuracy, reliability, and ease of use within the safety and operational constraints typically found at airports. The research also evaluated sampling plans and methods of expanding samples to produce estimates of annual activity.

The report summarizes the need for accurate aircraft operations counts and the challenges to obtaining these counts at many airports. It describes the research approach used to identify, test, and evaluate various aircraft operations counting techniques. The report then presents the research findings and suggests areas for further research. The report includes appendices that provide statistical backup for the research effort, an example of estimating aircraft operations from sample counts, a copy of *Statistical Sampling of Aircraft Operations at Non-Towered Airports* (FAA-APO-85-7), and graphics illustrating where tested technologies were placed at the study airports to help practitioners in positioning equipment at their facility.

The research found that methods of estimating aircraft operations using ratios of based aircraft or instrument flight plans, while simple and inexpensive, could not be supported by the test results. Basing operations estimates on actual samples of activity produces results that are significantly more accurate and defensible, with the most accurate sampling approach based on four 2-week samples (i.e., one in each season). Finally, the research found that the selection of a counting technology needs to consider the airfield layout and fleet mix, among other factors.

CONTENTS

SUMMARY

Evaluating Methods for Counting Aircraft Operations at Non-Towered Airports

Introduction

The objective of this research was to identify, test, and evaluate methods for obtaining aircraft operations counts at non-towered airports. Based on the requests of the ACRP panel for this project, findings from ACRP Synthesis 4 on this same topic, a literature review, a contacting initiative, and the budget allocated, three methods of estimating annual operations and four counting technologies were advanced for testing. The methods to estimate annual operations included (1) multiplying based aircraft by an estimated number of operations per based aircraft (OPBA), (2) applying a ratio of FAA instrument flight plans to total operations (IFPTO), and (3) expanding a sample count into an annual estimate through extrapolation.

In order to expand a sample into an annual count through extrapolation, the sample first has to be taken. This is typically done by some type of technology designed to count aircraft. The different aircraft counting technologies (used to obtain the sample count) that were advanced to the evaluation stage to determine their ability to count aircraft traffic included acoustic (both automated acoustical and sound-level meter acoustical), security/trail cameras, and video image detection with a transponder receiver.

The airports where the estimating methods were tested included multiple non-hub airports with FAA visual flight rules (VFR) towers with less than approximately 730 air carrier operations per year (defined in this study as the small, towered airport dataset—STAD). Since valid operations data does not exist for non-towered airports, these small, towered airports were used as a proxy for the comparison. The airports where the counting technologies (i.e., equipment) were tested included a multiple case study performed at Purdue University Airport (LAF), Indianapolis Executive Airport (TYQ), Paoli Municipal Airport (I42), and Eagle Creek Airpark (EYE).

Conclusion on Methods to Estimate Annual Operations

Overall, the research team concludes that, based on the study objectives and data, there were no practical and consistent OPBAs found or modeled at small, towered airports nationally or by climate region, even when considering the number of flight schools based at the airport. Therefore, the research team cannot recommend an OPBA or OPBA equation (based on the variables used in this study) for estimating annual operations at non-towered airports. Additionally, based on the data and study objectives, the research team concluded that there were no practical and consistent IFPTOs found at small, towered airports nationally or by climate region. Therefore the research team cannot recommend an IFPTO for estimating annual operations at non-towered airports. Accordingly, to estimate an airport's operations, the team recommends taking a sample of actual operations and extrapolating annual operations from the sample.

When taking a sample count, the research team studied four sampling scenarios and recommends sampling for two weeks in each season. This sample can be extrapolated by either a statistical extrapolation process or by use of seasonal/monthly adjustment factors developed from small, towered airports (i.e., STAD). The latter process assumes that the monthly and seasonal variations in traffic at small, towered airports are representative of non-towered airports. Statistical extrapolation uses sample data from the specific airport being studied. Based on this fact alone, the research team recommends using the statistical extrapolation process. This also removes the need for additional data and the influences of outside forces on the extrapolation process.

The statistical extrapolation method may appear more mathematically difficult than the monthly/seasonal extrapolation method. However, step-by-step instructions, examples, and forms are available in FAA-APO-85-7, *Statistical Sampling of Aircraft Operations at Non-Towered Airports*, which make it fairly straightforward. Additionally, Appendix B includes an example of how this is done.

Conclusion on Aircraft Traffic Counting Technologies

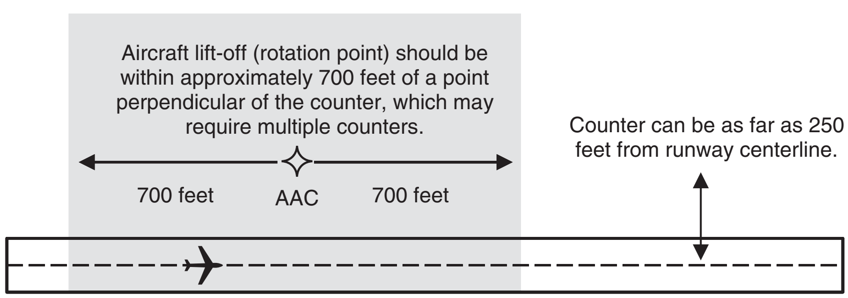
Automated acoustical counters (AAC) are best used at airports with single runways with runway safety areas of 500 feet or less that do not experience significant traffic by exceptionally quiet aircraft. They record takeoffs only. No aircraft information is provided. Accuracy rates of 90% or higher (up to 250 feet from runway centerline) can be achieved if the equipment is located properly and sufficiently tested. (Note: The FAA required submission of FAA Form 7460 for each unit placed and units had to be outside of the runway safety area.)

The aircraft lift-off point should generally be within approximately 700 feet of a point perpendicular of the counter to be consistently counted. (See Figure S-1.) Multiple counters are required for runways approaching 3,000 feet or more—this makes this option more labor intensive on longer runways. Approximate purchase cost at the time of the study was $4,800 each.

Exceptionally quiet aircraft are often missed more often than counted (e.g., Cessna 172 with Continental O-300 SER engine was missed at a distance of approximately 50 feet of the unit). These are typically small single engine piston aircraft. Jets, turbo props, and multi-engine piston aircraft are typically louder and are not missed as often.

Helicopters are harder to count because they do not have a uniform landing path; to be counted they have to fly over the general area of the counter to be detected. Airports with multiple runways will be difficult to count with consistent, acceptable accuracy.

Sound-level meter acoustical counters (SMAC) are best used at airports with single runways and runway safety areas of 150 feet or less. They record takeoffs only. No aircraft



Prepared by: Woolpert, Inc.

Figure S-1. Placement of AAC at airport runway.

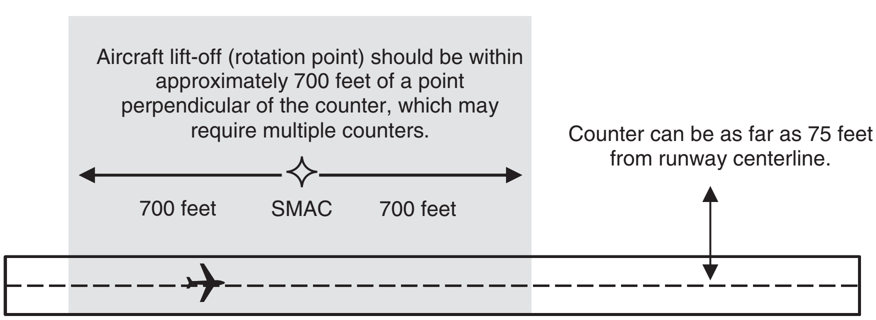
information is provided. Accuracy levels of 90% accuracy or higher can be achieved if the equipment is located properly, sufficiently tested, and generally not more than 75 feet from runway centerline. (Note: FAA required submission of FAA Form 7460 for each unit placed and units had to be outside of the runway safety area.)

The aircraft lift-off (rotation point) should generally be within approximately 700 feet of a point perpendicular of the counter to be consistently counted. (See Figure S-2.) Multiple counters are required for runways approaching 3,000 feet or greater—this makes this option more labor intensive on longer runways. (Approximate purchase cost at the time of the study was also $4,800 each.)

Exceptionally quiet aircraft are often missed at distances greater than approximately 50 feet of the runway centerline. (e.g., Cessna 172 with Continental O-300 SER engine). These are typically small single engine piston aircraft. Jets, turbo props, and multi-engine piston aircraft are typically louder and are not missed as often. Helicopters are harder to count because they do not have a uniform landing path—to be counted they have to fly over the general area of the counter to be detected. Airports with multiple runways will be difficult to count with consistent, acceptable accuracy.

Security/Trail Camera (S/TC) are best used at airports with a centralized terminal and hangar area with limited access points and little to no touch-and-go activity. A camera is needed at each access point to the runway. (Approximate purchase cost at the time of the study was $1,000 each.) Accuracy levels approaching 100% can be achieved for recording aircraft entering or exiting the runway environment; however, the units are not able to count touch-and-goes. Exceptionally slow moving aircraft may be missed. Counting aircraft this way is labor intensive because it requires manual tallying of the images. Information on aircraft type, make, and model can be obtained from the aircraft registration numbers by use of the FAA aircraft database. The units are a low-cost option for airports with very simple airfield configurations. (Note: FAA required submission of FAA Form 7460 for each unit placed and units had to be outside of the taxiway safety area.)

Video Image Detection (VID) and Automatic Dependent Surveillance-Broadcast (ADS-B) transponder receiver technology is best used at airports with centralized terminal and hangar areas with limited access points and little to no touch-and-go activity. Accuracy levels as high as 90% can be achieved for recording aircraft entering or exiting the runway environment; however, the ADS-B transponder receiver adds little to no value, considering the low equipage rate of the U.S. general aviation fleet with ADS-B out. (Note: General aviation includes all segments of flying except for airlines and military.) Additionally, the VID does not count touch-and-goes. This is the most expensive option for counting aircraft operations, but also the least labor intensive. (Approximate lease cost at the time of the study was $36,000 for



Prepared by: Woolpert, Inc.

Figure S-2. Placement of SMAC at airport runway.

two cameras and one receiver.) An annual service contract is required. (Note: FAA required submission of FAA Form 7460 for each unit placed and units had to be outside of the taxiway safety area.)

Summary

Sample counts can be costly and time consuming. The accuracy needed and the cost of the counts should be considered, along with the potential implications of the uses of the resulting annual operations estimates, to determine the appropriate sampling method for an individual airport. The preferred method selected by an individual airport may depend on the individual airport's situation.

CHAPTER 1

Introduction

Statement of Problem

Annual aircraft operations estimates are used in aviation system planning, airport master planning, environmental studies, aviation forecasts, and for a host of other reasons. At airports with air traffic control towers, aircraft operations are tracked and recorded by the air traffic controllers; however, most airports in the United States do not have air traffic control towers (FAA 2012). Such airports are generally known as non-towered, and they comprise the vast majority of the airports open to the public. Accordingly, unlike the larger, towered airports, these non-towered airports do not have readily available records on aircraft activity. Consequently, many state aviation agencies and some airports and metropolitan planning organizations (MPOs) have developed aircraft traffic counting programs to track airport activity at their airports, although many have not. Knowledge of the cost, accuracy, and complexity of the various methods for obtaining aircraft operations counts at non-towered airports is needed to help airports select the most appropriate method for their needs.

Purpose of Study

The objective of this research is to identify, test, and evaluate methods for obtaining aircraft operations counts at non-towered airports.

CHAPTER 2

Research Approach

The research project included five primary tasks:

1. Developing an amplified work program and identifying subsequent advances in aircraft operations counting technologies since the publication of *ACRP Synthesis 4: Counting Aircraft Operations at Non-Towered Airports*.
2. Contacting states, airports, and MPOs about their counting practices.
3. Developing the test program.
4. Conducting the test program.
5. Producing a final report.

These tasks are outlined in greater detail in the following pages and sections of this report.

Tasks

Task 1: Developing amplified work program and identifying subsequent advances in aircraft operations counting technologies since the publication of ACRP Synthesis 4.

Task 1 involved reviewing the original work program provided during the request for proposals and updating it based on committee comments as necessary. After the amplified work program was accepted, ACRP Synthesis 4 was reviewed to glean information about previous research performed by TRB and others on the research topic. Then, a literature review was conducted to identify any new technologies and methods that had been implemented subsequent to the publication of ACRP Synthesis 4. It was not the intent of this study to redo this literature review, but rather to add to it the review of any literature that had occurred since ACRP Synthesis 4, or that may have become available through more powerful research engines. The updated literature review included a search of the academic and research literature related to counting aircraft traffic operations at non-towered airports, as well as the available literature resulting from national and international aviation conferences, all of which was scrutinized for salient points, common elements, and best practices.

The literature review revealed two recent efforts at recording non-towered airport operations. One was entitled *X-band Radar: Radar for Monitoring the Airport Environs* (Hartfiel 2011). This report was a student project for submission to the FAA Real World Design Competition. It investigated the utilization of X-band off-the-shelf commercial radar typically used for a private watercraft, along with associated hardware and software, to collect aircraft movement data. Unfortunately, the project team did not receive FAA and Federal Communication Commission (FCC) approval for the installation of the X-band radar equipment so it was not identified as a current technology to evaluate. One special concern revealed in the study was the power and spectrum output of the radar and the potential for interference with aircraft and air traffic control operations.

Another effort, also a result of FAA Real World Design Competition, was titled *Aviation Operations Monitoring System* (Angelini 2011). It proposed the installation of Radio Frequency Identification (RFID) transmitters on general aviation aircraft along with airport installation of RFID readers in order to record aircraft operations. (Note: General aviation includes all segments of flying except for airlines and military.) The biggest issue for this technology is that it required the installation of RFID transmitters in all the aircraft, which presents similar challenges as found with ADS-B in that most general aviation aircraft owners would not voluntarily install the equipment. This is especially true in this case where no benefit to the owner would result from the installation. While this system reportedly would accurately count aircraft passing within its range of view, it would have similar challenges to other systems in determining the phase of operation and actual counting applicability. For these reasons, it also was not included as a current technology to evaluate.

Task 2: Contacting States, Airports, MPOs

After the literature review was performed, the aviation officials for each state within the United States were contacted (contacting initiative) by phone and asked to fill out an online survey regarding their practices for counting traffic at non-towered airports. They were also asked if they knew of any entities within their state that were conducting their own airport traffic counting program and, if they did, those entities were also contacted. In some cases the individuals contacted did not want to participate in the online survey, so if willing, their information was collected during a phone call or by information on their respective entity's website or other published information (e.g., state aviation system plan). If their responses revealed a new method of counting aircraft from those identified in ACRP Synthesis 4, they were subsequently contacted directly for more information.

The contacting initiative revealed that, by and large, the vast majority of state aviation officials collect traffic counts by simply asking the airport manager, fixed-based operation (FBO), or other entity associated with the airport what the annual operations are, which typically consists of an educated guess. Many entities base their estimates on a valid data source, but the data source itself does not contain all aircraft so it intrinsically excludes traffic (e.g., Flight Aware or pilot sign-in log books).

A new method for estimating aircraft operations was revealed in the contacting initiative: one airport estimated its total operations by adding three VFR flights to each instrument flight rules (IFR) flight plan for the year to produce an annual estimate, but admits the ratio is an estimate. This method is referred to in this report as the IFPTO method from this point forward.

The contacting initiative also revealed how states and other entities were using operations data, which included a variety of reasons:

- Airport control tower justification
- Airport development project justification
- Airport Master Record (Form 5010)
- Airport operations fleet mix
- Aviation forecasts
- Budget funding justification
- Community relations
- Activity changes (increasing/decreasing) at airports
- Economic impact statements
- Environmental Assessment or Impact Documentation
- Instrument approach procedure development justification
- Lease or curfew compliance
- Master plan updates
- Measure of performance
- Runway pavement life spans

The most widespread use of the operations data was for inclusion on the airport's FAA Airport Master Record Form 5010. Aviation forecasting and justification for airport development projects were also listed as some of the most common uses of the data.

The contacting initiative revealed that, generally, states, planning entities, and airports are interested in a user-friendly, accurate, and cost-effective counting/estimating methodology. While sampling operations with an acoustical counter ranked as the favored method of the FAA (FAA 2007), only five entities utilized this method. In fact, many state aviation officials had abandoned using acoustical equipment because either they felt they weren't accurate, they couldn't verify their accuracy, the equipment was old, or it was in a state of disrepair.

The contacting initiative also revealed that most entities that take sample counts do not use a statistical process for extrapolating the results into an annual estimate. Rather, they use a seasonal or monthly adjustment factor based on towered airport operations data. Several entities estimate operations by use of an estimated OPBA method, but there is no consistent base value used, as they ranged from 100 to 750 operations per based aircraft.

While VID systems were thought to offer the most information about the aircraft traffic, including aircraft identification numbers and aircraft make and model (which is most useful when critical aircraft need to be identified for justification of runway extensions), none of the responders in the contacting initiative indicated use of this system for counting purposes. Airports that had installed VID systems did so for other reasons. One consideration as to why VID systems are not being used to count aircraft traffic is the cost. While they provide information on aircraft identification numbers, make, model, weight, operations, etc., they are costly (anywhere from $50,000 to over $150,000 depending on airport layout) and require a monthly charge from the service provider to obtain the data.

Task 3: Developing the Test Program

The test program developed in the amplified work program was updated based on the results of the contacting initiative. The completed literature review and contacting initiative did not uncover any significant new information about airport operation counting and estimating methods being practiced today except for the use of the IFPTO method, which was added to the research.

Based on the requests of the ACRP Project 03-27 panel, findings from ACRP Synthesis 4, the literature review, the contacting initiative, and the budget allocated for the project, three methods of estimating annual operations and four counting technologies were advanced for testing. The methods to estimate annual operations included (1) multiplying based aircraft by an estimated number of OPBA, (2) applying a ratio of FAA IFPTO, and (3) expanding a sample count into an annual estimate through extrapolation. In order to expand a sample into an annual count through extrapolation, the sample first has to be taken. This can be done by a person physically counting aircraft operations, but is more typically done by some type of aircraft counting technology. The different aircraft counting technologies (to obtain the sample count) that were advanced to the evaluation stage to determine their ability to count aircraft traffic at non-towered airports included acoustic (both automated acoustical and sound-level meter acoustical), security/trail cameras, and VID with a transponder receiver. These methods and technologies are described in detail in the following sections.

The airports where the estimating methods were tested included multiple non-hub airports with FAA VFR towers with less than approximately 730 air carrier operations per year. (See Chapter 3 for information of these airports.) The airports where the counting technologies (i.e., equipment) were tested included Purdue University Airport (LAF), Indianapolis Executive Airport (TYQ), Paoli Municipal Airport (I42), and Eagle Creek Airpark (EYE). A summary of the methods and locations is shown in Table 2-1.

Estimating Methods

The three methods of estimating annual operations advanced for testing included OPBA, applying a ratio of the IFPTO, and extrapolating from a sample count. These methods were tested by climatic region using a dataset derived from FAA towered airport records. The dataset is described here:

Dataset Sources: The data sources for this analysis were the FAA Terminal Area Forecast (TAF) and the FAA Operations Network (OPSNET) databases from 2006 to 2010. The TAF includes historical and forecast statistics on passenger demand and aviation activity at U.S. airports. The TAF contains historical and forecast data for enplanements, airport operations, and based aircraft. Once published the TAF remains constant until its next publication with the only exceptions being significant traffic shifts by major airlines, or the revelation of a significant historical data error. This database was used for enplanements.

To augment the TAF, OPSNET data was used for operations because OPSNET is the official source of National Airspace System air traffic operations and delay data. OPSNET does not include data on enplanements, which is why the TAF was also used.

Note that towered airports actively count and report operations data via the air traffic controllers, while non-towered typically do not. To test these three methods described above, estimated operations must be compared to actual operations. This can only be done where annual operations are known, which are at towered airports. Therefore, TAF and OPSNET data for certain small, towered airports was used in this part of the research as a proxy for non-towered airports. Small, towered airports were defined, for this study, by the following criteria:

- Non-hub public use airport with FAA VFR tower or FAA contract tower;
- Less than 10,000 annual enplanements (i.e., non-primary airports); and
- Less than 730 air carrier operations per year (i.e., an average of one air carrier flight per day).

Table 2-1. Counting methods tested and locations summary.

METHOD		
A. Equipment - Sample Count: Expand sample count to annual count or count full year.	**B. Operations Per Based Aircraft (OPBA)** Estimate annual operations as a product of based aircraft.	**C. Instrument Flight Plans to Total Operations (IFPTO)** Estimate annual operations as a ratio of flight plans filed.
1A Sound-Level Meter Acoustical Counter. Test Locations: LAF, TYQ, EYE, I42	FAA as source for historic tower counts and based aircraft.	FAA as source for historic tower counts and instrument flight data.
1B Automated Acoustical Counter Test Locations: LAF, TYQ, EYE, I42.	**Test Locations:** Multiple FAA VFR Towered airports across the U.S.	**Test Locations:** Multiple FAA VFR Towered airports across the U.S.
2 Security/Trail Camera Test Location: TYQ, EYE, I42.		
3 Video Image Detection - Test Location: TYQ.		
4 Transponder Receiver - Test Location: TYQ.		

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Non-hub airports were chosen because they are more likely to *not* have a large amount of commercial service and would better reflect non-towered airports. Within this grouping, FAA VFR tower and contract tower airports were chosen because these airports were assumed to more closely resemble non-towered airports than towered airports that were busy enough to warrant the installation of radar. Airports with less than an average of 730 air carrier operations were chosen because 730 would represent approximately two air carrier operations per day (one takeoff and one landing) and this would more closely represent non-towered airports than airports that experience regular and consistent air carrier operations. The application of this criteria resulted in 205 airports being included in what this research labeled the STAD.

Climate data was obtained from the National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center. Through their climate analysis, they have identified nine climatically consistent regions within the contiguous United States, which were used in this analysis. (See Table 2-2.)

OPBA. When using this method, operations are projected as a product of based aircraft by multiplying an airport's based aircraft by an estimated number of OPBA. The objective of analyzing this method was to determine if there was a number that could be used by airport management/planners to multiply by their number of based aircraft to obtain a relatively accurate estimate of annual airport operations. To be evaluated, the operations estimated using the OPBA method had to be compared to airports with known annual traffic and based aircraft. As stated previously, since valid operations data do not exist for non-towered airports, small, towered airports (i.e., STAD) were used as a proxy for the comparison. Each airport's recorded operations for five historic years were divided by the number of based aircraft at the facility for the same five historic years (2006–2010). The states were divided into their nine climate regions defined by the NOAA, National Climatic Data Center and the airport's region noted. The population of the associated city of the airport was also determined by accessing U.S. Census data and noted. The research team then determined if there was a consistent number(s) of OPBA that occurred at these facilities and if it varied by climate or population.

Table 2-2. States and NOAA climatic regions.

State	Climatic Region	State	Climatic Region
AK	Alaska	MT	West North Central
AL	Southeast	NC	Southeast
AR	South	ND	West North Central
AZ	Southwest	NE	West North Central
CA	West	NH	Northeast
CO	Southwest	NJ	Northeast
CT	Northeast	NM	Southwest
DE	Northeast	NV	West
FL	Southeast	NY	Northeast
GA	Southeast	OH	Central
HI	Hawaii	OK	South
IA	East North Central	OR	Northwest
ID	Northwest	PA	Northeast
IL	Central	RI	Northeast
IN	Central	SC	Southeast
KS	South	SD	West North Central
KY	Central	TN	Central
LA	South	TX	South
MA	Northeast	UT	Southwest
MD	Northeast	VA	Southeast
ME	Northeast	VT	Northeast
MI	East North Central	WA	Northwest
MN	East North Central	WI	East North Central
MO	Central	WV	Central
MS	South	WY	West North Central

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IFPTO. When using this method, operations are projected as a ratio of IFPTO. Since IFR operations are tracked and recorded by the FAA for all airports (VFR operations are not) and total operations are known for towered airports, total operations could theoretically be estimated from IFR operations if a consistent ratio existed between them. The objective of analyzing this method was to determine if there was a ratio of IFR to VFR operations that could be used by airports to obtain a relatively accurate estimate of annual airport operations. To test this method, annual IFR traffic for the same small, towered airports (i.e., STAD) described in the OPBA exercise were compared to their total traffic using the same dataset sources described above. Each airport's annual operations were divided by the number of IFR operations for the facility for five historic years (2006–2010). The climate region of the airport was also acquired and noted. The research team then determined if there was a consistent ratio of IFR flight plans filed to total operations that occurred at these facilities and if it varied by climate.

Extrapolation. When using this method, operations are projected by expanding a sample count into an annual estimate. When sample counts of aircraft operations are taken at an airport, the counts are typically extrapolated into annual operations estimates using one of two different types of extrapolation methods: (1) statistical extrapolation and (2) monthly/seasonal adjustment factor extrapolation.

Statistical Extrapolation. At many airports, activity will vary due to day of week, weather, and season. The goal is to take a sample(s) that captures these differences. Previous research (FAA-APO-85-7, *Statistical Sampling of Aircraft Operations at Non-Towered Airports*) has indicated that the most accurate and cost-effective way to do this is to sample traffic for two weeks for each of the airport's seasons and extrapolate that into an annual estimate. However, not all entities do this. To test different sampling periods, random samples of daily historic 2010 tower operations from FAA OPSNET for different timeframes was gathered for one of the STAD airports in each of the nine climate regions and statistically extrapolated into annual estimates using the method in FAA-APO-85-7. The random samples included the following timeframes:

1. One week in each season (number of seasons depends on climate).
2. Two weeks in each season (number of seasons depends on climate).
3. One month in spring, summer, or fall.
4. One month in winter.

The research team then compared the estimated operations to the actual operations.

Monthly/Seasonal Adjustment Factors. The contacting initiate revealed that rather than using statistical extrapolation, some entities use a seasonal or monthly adjustment factor to expand an airport's sample into an annual estimate. For example, an entity believes that fifteen percent (15%) of the year's operations happen in July because that is the average for all the towered, general aviation (GA) airports in its state. If it samples traffic at a non-towered airport for the month of July, its sample would account for 15% of the total annual operations and it would compute its total estimated operations accordingly.

To test the monthly/seasonal adjustment factor, the percentage of operations that occurred in each month was calculated for each region based on the airports selected in the previous exercise. The random samples of operations for the same sample periods identified in the statistical extrapolation exercise described above were then extrapolated using these monthly percentages. The research team then compared the estimated operations to the actual operations.

Counting Technologies

As stated earlier, in order to expand a sample into an annual count through extrapolation (be it through statistical or monthly/seasonal adjustment factor extrapolation), the sample first has to be taken. This is often done through the use of some type of technology designed to count aircraft operations. This research looked at four different types of technologies: acoustic, security/trail cameras, VID, and ADS-B transponder receivers. The acoustic aircraft counters are designed to record takeoffs, but not landings. The underlying assumption is that for every takeoff there is a landing, so a total count is produced by doubling the takeoffs recorded. The security/trail cameras record traffic that passes in front of them and the images are then manually tallied. The VID equipment works on the same principle, but is automated and requires an annual service contract. It captures an image of the aircraft N-number as it passes by the camera and the service provider analyzes the image and provides detailed information about the aircraft. To augment the capability of its VID system, the service provider for the equipment tested in this study included an option for a simple transponder receiver programmed to detect ADS-B and Mode S (transponders that support Traffic Collision Avoidance System) transmissions that met certain criteria.

This identified equipment was evaluated in a multiple case study using four airports. A long-term study of all the equipment was performed at TYQ, where the equipment was left in place for approximately 7 months to determine its durability. The study also determined how the equipment would perform in both warm and cold months and how much information could be stored before data had to be downloaded.

Short-term accuracy tests were also performed at TYQ, LAF, I42, and EYE for the acoustic counters and TYQ, I42, and EYE for the security/trail cameras. Because of the expense of leasing and installing the video imaging detection equipment and transponder equipment, it was only tested at TYQ. (Note: The FAA would not approve testing the VID or the security cameras at LAF because they would need to be located within FAA restricted set-backs to work.)

The information from the installation process, durability study, and short-term studies were used to rate each piece of equipment on the following criteria:

- Principle(s) of operation and intended use
- Computer requirements
- Data provided
- Ease of portability
- Durability
- Ease of installation and airport impacts
- Maintenance and operation
- Ease of data retrieval
- Performance in various weather and lighting conditions
- Service contract requirements
- Cost
- Accuracy

The data from the accuracy tests were compared to visual observations, which included recording each airport operation, the aircraft N-number, aircraft type (e.g., single engine, multi-engine, turbine/jet, helicopter), the date, the time, and type of operation (i.e., landing, takeoff, touch-and-go.) These data were then compared to the data from each aircraft counter (or group of counters as appropriate) and differences noted. The percentage of error for each counter (or group of counters, as appropriate) was computed.

It is important to note that the FAA determined that any equipment installation on the airport, even if it were temporary and outside the runway safety area, required an FAA approval (through the filing of an FAA Form 7460) in order to be in compliance with Title 14 of the Code of Federal Regulations (CFR) Part 77. In the case of this research, a Form 7460 was needed for each piece of equipment at each airport. The locations of the equipment are detailed in the results section and Appendix D, which include airport diagrams.

Task 4: Conducting the Test Program

This task involved implementing the research program developed in Task 3. The goals of the program were to evaluate the estimating methods and counting technologies at different airports, giving consideration to their unique characteristics where appropriate, and compare actual operations to estimated or counted operations.

Task 5: Producing the Final Report

This task involved the creation of this final project report.

Limitations and Assumptions of the Study

A comparison of estimated results to observed data is routinely used as a way to measure accuracy of a model. In the case of annual airport operations, the only way to acquire observed data at non-towered airports would be to physically watch and record each operation for a full year. This practice is not feasible or practical, which is the underlying need for this current research project. Because of this limitation, the methods described herein for this current research project are often compared to small, VFR towered airport data. (For a description of the airports used in the analysis, please refer to dataset sources under Task 3.) (Note: VFR towers are airport traffic control towers that provide takeoff and landing services only. They do not provide approach control services. Aircraft on IFR flight plans can still take off and land at an airport with a VFR tower.)

When using small, towered airports in the analysis, an assumption is made that traffic behavior is similar from VFR towered airports to non-towered airports. In the past, towered airports were believed to have more consistent traffic due to more and better instrument approach procedures serving them. Any potential differences that may exist between towered and non-towered airports have theoretically narrowed over time with the introduction of global positioning system (GPS) guided instrument approaches to a vast spectrum of non-towered airports. Where the better instrument approaches may have normally been found at towered airports, GPS technology has increased the utility of most airports during inclement weather, so weather conditions are less of a differentiator now as compared to years past, making the majority of publicly owned airports similar in approach capabilities.

According to the FAA Global Navigation Satellite System (GNSS) Program Office, there were 2,664 Wide Area Augmentation System (WAAS) capable airports in the United States as of May 31, 2012, and 80% of these were non-Part 139 FAA certificated airports. Most GA, non-towered airports are also typically non-Part 139. (Note: WAAS provides augmentation information to GPS receivers to enhance the accuracy and reliability of position estimates and allows for very accurate instrument flight procedures into airports). While some of the 80% will have towers, the instrument approach differentiator between towered and non-towered airports has diminished significantly.

It is also important to note that some of the data on the small, non-towered airport comes from the FAA TAF and OPSNET databases. The most recent year where the TAF included actual and not forecast data at the time this analysis was initiated was 2010. Therefore, all use of FAA TAF data included 2010 and earlier. To remain consistent, data used from FAA OPSNET also included only 2010 and earlier.

CHAPTER 3

Research Findings

As detailed in the previous chapters, this research involved testing three different methods of estimating an airport's annual operations and also testing five different aircraft traffic counting technologies (that can be used to take samples that are then extrapolated into an annual operations estimate for the airport). The methods for estimating annual operations that were tested included the following:

- Multiplying based aircraft by an estimated number of OPBA,
- Applying a ratio of FAA IFPTO, and
- Expanding a sample count into an annual estimate through extrapolation.

Aircraft traffic counters tested included the following:

- AAC (portable acoustic counter),
- SMAC (portable acoustic counter),
- S/TC (portable camera with infrared night vision), and
- VID System with ADS-B transponder receiver.

The results of the tests are described in the following section: Methods for Estimating Annual Airport Operations and Aircraft Traffic Counters Technologies Evaluated.

Methods for Estimating Annual Airport Operations

Estimates of annual operations for non-towered airports using three methods are analyzed in this research: (1) multiplying based aircraft by an estimated number of OPBA, (2) Applying a ratio of FAA IFPTO, and (3) extrapolation of a sample count. As non-towered operations data is not based on tower counts, a dataset containing information on small, towered airports was developed for use in the analysis of the above estimating methods. (See Chapter 2, Estimating Methods, for a full description of the dataset.) Data reported by these small, towered airports was used to compare their reported annual operations to their estimated annual operations using the above three methods.

Summary of Data Sources and Descriptions

Since there is no valid source for counts of operations data at non-towered airports, data on small, towered airports were used as a proxy for non-towered airports in the analysis of methods for estimating annual operations. Chapter 2 includes a description of the STAD developed for this research project.

The sources for the data on the STAD airports used in this analysis were the FAA TAF and the FAA OPSNET databases from 2006 to 2010. To more accurately describe the operations at a non-towered airport, total general aviation operations (Total GA OPS) at small, towered airports were used in the analysis rather than total operations.

Table 3-1 identifies the name of each variable, its description, and its sources used in this analysis. This table may be referred to while reading the analysis that follows.

Averaging the Data for Years 2006–2010

For each of the 205 airports, data from each of the 5 years from 2006 to 2010 were collected and stored in the STAD. The research team analyzed the data to see if an average of the 5 years of data for each airport could be used instead of the data from each year. An average of the 5 years of airport data allows for statistically accurate analysis of the 205 airports in the dataset, and simplifies the statistical analyses and outputs. Based on the results of statistical tests described in Appendix A, the average of the operations data for each airport were determined by the research team to be acceptable for use in the analysis. As a result, the Total GA OPBA ratios for the 5 years for each airport were averaged to obtain the Average GA OPBA (AvgOPBA in Table 3-1) for each of the small

Table 3-1. Variables and descriptions of sources.

Variable	Description	Source
AvgOPBA	Average general aviation OPBA for each airport 2006-2010.	OPBA calculated from OPSNET and TAF data
Enp	Enplanements or revenue passenger boardings.	TAF
OPS	Average general aviation operations for each airport 2006-2010.	OPSNET Data
AvgPop	The average population for the years 2006-2010 for the city or town surrounding the airport.	U.S. Census. United States Census Bureau. Population Estimates 2000-2009 http://www.census.gov/popest/data/cities/totals/2009/SUB-EST2009-4.html United States Census Bureau. 2010 Population Finder http://www.census.gov/popfinder/index.php
Pop Scaled	The average population scaled by 10,000 for the city or town surrounding the airport for the years 2006-2010.	AvgPop/10,000
NFS	The number of flight schools at the airport.	AOPA (Training and Safety) http://www.aopa.org/learntofly/school/index.cfm
FS Y/N	The presence of a flight school. (1=Yes and 0=No)	AOPA (Training and Safety) http://www.aopa.org/learntofly/school/index.cfm
CTHrs	Yearly hours of control tower operations.	FAA Airport Facility Directory. (March 2013 data as no historical data was available)
C	1 for Central; 0 for other regions.	Definition from NOAA and data from OPSNET
EN	1 for East North Central; 0 for other regions.	Definition from NOAA and data from OPSNET
NE	1 for Northeast; 0 for other regions.	Definition from NOAA and data from OPSNET
NW	1 for Northwest; 0 for other regions.	Definition from NOAA and data from OPSNET
S	1 for South; 0 for other regions.	Definition from NOAA and data from OPSNET
SE	1 for Southeast; 0 for other regions.	Definition from NOAA and data from OPSNET
SW	1 for Southwest; 0 for other regions.	Definition from NOAA and data from OPSNET
CM	1 for Commercial airport; 0 for GA or RL	National Plan of Integrated Airport Systems
RL	1 for Reliever airport; 0 for CM or GA	National Plan of Integrated Airport Systems

Note: West is not defined here, but it occurs when all other regions are set to 0. GA is not defined here, but it occurs when CM and RL are set to 0. North West Central is not included because there are no airports that met the criteria for inclusion in this dataset from this region.

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non-towered airports. AvgOPBA was used in the following regression analyses.

OPBA Method to Estimate Annual Airport Operations

The first method analyzed for estimating operations is the OPBA where the number of based aircraft at an airport are multiplied by an estimated number of operations per based aircraft. To use this method, the estimated number of OPBA is needed. FAA Order 5090.3C, *Field Formulation of The National Plan of Integrated Airport Systems* (NPIAS) gives the following general guidelines for OPBA values:

- 250 OPBA for rural general aviation airports with little itinerant traffic.
- 350 OPBA for busier general aviation airports with more itinerant traffic.
- 450 OPBA for busy reliever airports.
- 750 OPBA in unusual circumstances (e.g., busy reliever with high itinerant operations).

The objective of this research task was to determine if there was a consistent number(s) of OPBA that occur at small, towered airports (i.e., STAD), if it varied by climate or population, and if having a flight school affected this number. Initial analysis revealed that an extremely large range of OPBAs exist for the STAD airports overall and by region, and practical use of any averages would not produce confident results. (See Table 3-2.) With this in mind, the research team attempted to actually model total OPBA through regression analysis to determine if an equation could be produced that offered better results. To do this, the research team modeled total OPBA at non-towered airports from operations data at small, towered airports using information about the population, NOAA climate region, and flight schools.

Table 3-2. Summary of small, towered airport data by region used in this study.

NOAA Climate region	Number of airports	AvgBA per region	Avg Ops per region	AvgPop	OPBA mean	OPBA median	OPBA 95% Confidence Interval for the median	OPBA range Low	OPBA range High
Alaska	1	965.8	152,018	283,382	157.40	157.40	NA	NA	NA
Central	33	141.01	49,187	162,441	429.54	360.13	(298.02, 426.85)	201.75	1,015.54
E. N. Central	13	188.52	67,823	260,933	473.92	462.29	(266.65, 550.52)	177.42	798.85
Hawaii	1	22.80	104,224	13,689	4,771.68	4771.6	NA	NA	NA
Northeast	28	187.06	72,081	353,687	432.95	408.37	(351.95, 504.20)	225.91	828.52
Northwest	8	202.90	80,577	224,704	382.95	779.38	(264.80, 453.03)	219.87	779.38
South	41	154.19	65,312	352,947	597.89	338.00	(302.52, 522.53)	132.17	2,481.89
Southeast	38	212.66	95,457	171,804	561.74	439.42	(338.62, 572.66)	190.89	2,491.54
Southwest	15	394.01	16,802	391,318	487.23	396.66	(336.31, 646.39)	192.52	819.86
West	27	381.98	124,391	388,546	370.13	326.30	(282.28, 362.85)	139.69	875.89
W.N. Central	0	NA	NA	NA	NA	NA	NA	NA	NA
Overall	205	222.35	85,890	394,118	501.68	377.78	(350.30, 412.86)	132.17	4,471.68

Legend: Avg = Average BA = Based Aircraft Ops = Operations OPBA = Operations per Based Aircraft NA = Not Applicable
Note: There are no airports from the West North Central region that meet the selection criteria for airports to be included in the dataset.

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Table 3-2 summarizes the OPBAs for the 205 STAD airports that were used in this study.

Analysis

Regression analysis was performed to determine if there is a consistent number(s) of OPBA that occur at STAD airports. If there is a consistent OPBA, then that factor could be applied to non-towered airports to estimate annual operations. The regression analysis also considered if the OPBA varied by climate or population and if having a flight school affected this number. Regression analysis of the data was used to determine the effect these variables have on AvgOPBA in the STAD. The analysis includes:

A. Full model and reduced model using AvgOPBA.
B. Transformation of AvgOPBA and average based aircraft (AvgBA).
C. Full model and reduced model using transformed data.
D. Full model and reduced model using operations (OPS).

A. Full model and reduced model using AvgOPBA. First, the full model regression was created using AvgOPBA as the variable to be estimated by the regression equation. The variables used in the full model regression analysis are:

- AvgOPBA,
- AvgBA,
- Number of Flight Schools at the airport (NFS),
- Flight School Yes/No (FS Y/N),
- Based Aircraft (BA),
- Population (Pop Scaled),
- Yearly Hours of Control Tower Operations (CTHrs),
- Central (C), East North Central (EN), Northeast (NE), South (S), Southeast (SE), Southwest (SW) climate regions,
- Commercial airport (CM),
- Reliever airport (RL)

(see Table 3-1 for descriptions of these variables).

A reduced model was also developed. A reduced model is used to filter out uninformative variables and thereby, simplify the model.

While the regression equations appeared significant in statistical terms, further analysis revealed that the equations found to estimate OPBA did not explain enough of the airport data to be practically useful. In addition, the regression did not meet the necessary assumptions for statistical validity (e.g., normality, linearity, independence, etc.). Therefore, full model and reduced model regression using AvgOPBA were rejected. (See Appendix A for details on the full statistical analysis.)

B. Transformation of AvgOPBA and AvgBA. Since the full model and reduced model regression described above did not meet the necessary assumption for statistical validity, the data was "transformed" to see if it would better meet the required statistical assumptions. (Note: Transformed data changes the scale and may make relationships more visible than with non-transformed data.)

Based on the statistical analyses detailed in Appendix A, the data for AvgOPBA and AvgBA were changed algebraically in a way that the statistical assumptions could be met. Instead of AvgOPBA and AvgBA, the logarithms of these numbers were used. Analysis of the transformed data determined that it met the required statistical assumptions and, therefore, was valid to use in building a model, which is described in Part C.

C. Full model and reduced model using transformed data. Based on the findings in Part B, two models were developed:

1) Full model regression using logarithm data and all of the variables described earlier.

$$\begin{aligned}\text{log10AvgOPBA} = 3.95 - 0.681\ \text{log10AvgBA} \\ + 0.000215\ \text{Pop scaled} + 0.0246\ \text{NFS} \\ + 0.0206\ \text{FS Y/N} + 0.000036\ \text{CTHrs} \\ - 0.153\ \text{C} - 0.0921\ \text{EN} - 0.0716\ \text{NE} \\ - 0.0421\ \text{NW} - 0.0704\ \text{S} + 0.0079\ \text{SE} \\ + 0.118\ \text{SW} - 0.0652\ \text{CM} - 0.0176\ \text{RL}\end{aligned}$$

2) Reduced model regression using logarithm data with certain variables removed.

$$\begin{aligned}\text{log10AvgOPBA} = 3.94 - 0.621\ \text{log10AvgBA} \\ + 0.000232\ \text{Pop scaled} + 0.0279\ \text{NFS} \\ - 0.0797\ \text{C} + 0.0631\ \text{SE} + 0.169\ \text{SW}\end{aligned}$$

The regression for the full and reduced model were statistically significant at the 95% level (alpha equals 0.05). The R-Sq(adj) equaled 51% and 50.4% respectively. (Note: The adjusted R-Squared is the proportion of the total variation of outcomes explained by the model taking into consideration the number of variables in the model.) The analysis of the transformed data using a reduced model regression is valid based on the residual plots (refer to Appendix A for more detail), along with its ability to meet the other regression assumptions.

The reduced model has a very slight reduction in R-Sq(adj) than the full model (50.4% compared to 51%). However, the reduced model is preferable to the full model because it uses only six variables, while the full model uses 14 variables. Practically speaking, to use this equation to estimate the OPBA, the only data a person needs are the number of based aircraft, the population (divided by 10,000) for the city or town surrounding the airport, the number of flight schools at the airport, and the NOAA region for the airport. (An example of a calculation is provided in the Appendix A.) However, this equation only accounts for approximately 50% of the behavior of annual OPBA, and therefore, it may not provide useful estimates in a practical application. If only approximately 50% of the variation of the AvgOPBA is explained by the variables in the equation (i.e., flight schools, population, climate, and airport category), then large variations from actual to estimated operations are likely to occur. Therefore, use of this model is not recommended.

D. Full model and reduced model using OPS. Because using AvgOPBA did not prove to be a relatively accurate way to estimate operations using the variables described in Part A, the research team chose to explore a different approach. While the research problem was to determine if there was a consistent number of OPBA that could be used to estimate an airport's annual OPS, the ultimate goal is to estimate the annual OPS, not the OPBA. Therefore, analysis of a regression model for estimating OPS rather than OPBA was performed. Previous research (GRA, Inc. 2001) has shown that statistical models of operations may be more descriptive than models of OPBA.

In this analysis, full and reduced regression models using OPS were analyzed using the same variables as described in Part A.

Full Model Equation:

$$\begin{aligned}\text{OPS} = 8321 + 185\ \text{AvgBA} + 5185\ \text{NFS} + 1315\ \text{FS Y/N} \\ + 43.3\ \text{Pop Scaled} + 3.39\ \text{CTHrs} - 19462\ \text{C} - 11778\ \text{EN} \\ - 9125\ \text{NE} + 3418\ \text{NW} - 9397\ \text{S} + 5062\ \text{SE} + 45472\ \text{SW} \\ - 2670\ \text{CM} + 3353\ \text{RL}\end{aligned}$$

Reduced Model Equation:

$$\begin{aligned}\text{OPS} = 16535 + 199\ \text{AvgBA} + 5174\ \text{NFS} + 44.1\ \text{Pop scaled} \\ + 14880\ \text{SE} + 52389\ \text{SW}\end{aligned}$$

Both the full and reduced model regression equations were statistically significant at the 95% level (alpha equals 0.05). The R-Sq(adj) was found to be 64.6 and 65.3%, respectively. However, this equation only accounts for approximately 65% of the behavior of annual operations, and therefore, it may not provide useful estimates in a practical application. In addition, neither equation met the necessary assumptions for statistical validity. Therefore, full model and reduced model regression using OPS were rejected. (See Appendix A for details on the full statistical analysis.)

Conclusion

Overall, the research team concludes that based on the study objectives and data, there were no practical and consistent OPBAs found or modeled at STAD airports that can be used to estimate annual operations nationally or by climate region at non-towered airports, even when considering the number of flight schools based at the airport. From all the models analyzed, only the full and reduced model using transformed data (i.e., log10AvgOPBA and log10BA) met the necessary assumptions for statistical validity. However, the two regression equations developed for them only accounted for about 50% of the behavior of annual operations—that is, they did not explain a high proportion of the variability in the airport operations data tested, and therefore are unable to predict airport operations with high certainty. (See Appendix A for details on the full statistical analysis.)

IFPTO Method to Estimate Annual Airport Operations

The second method analyzed for estimating operations is calculating them as a ratio of instrument flight plans filed to total operations. The objective of this research task was to determine if a consistent ratio of IFR flight plans filed with the FAA to total operations (IFPTO) occur at small, towered airports, and if it varies by climate. Chapter 2 includes a description of the STAD developed for this research project.

Analysis

The total operations over the years 2006 to 2010 were averaged to obtain Avg GA OPS for each of the STAD airports. The General Aviation IFR flight plans over the years 2006 to 2010 were also averaged to obtain Average Total General Aviation IFR (Avg GA IFR). The IFPTO was calculated by dividing Average Total GA IFR flight plans by Avg GA OPS. In this task, the airports in the STAD were reduced from 205 to 202 for the following reasons. Alaska and Hawaii were removed because there was only one airport in each region. Additionally, the West North Central Climate Region was removed because it had no airport in the dataset. One airport in the South Climate Region was removed because it had no IFR flight plans (San Marcos Municipal-HYI); therefore, an IFR to total operations ratio could not be computed for it.

Table 3-3 contains the analysis of the 202 STAD airports in the final dataset. Figure 3-1 is a summary of the descriptive statistics for the dataset. The average IFPTO of all the airports analyzed is approximately 0.13. The lowest IFPTO of all the airports was 0.003, while the highest was 0.55. This range is about four times the average IFPTO in the dataset. It is suspected that this range would not be considered consistent or useful to airport managers because of its wide span.

For instance, if a non-towered airport determines that its number of IFR plans for a year is 1,000, then an estimate of total operations using the average of 0.13 IFPTO would be calculated as 7,692 total operations. Using the low end of the IFPTO range (0.003), total operations would be calculated as 333,333. Using the high end of the IFPTO range (0.55), total operations would be calculated as 1,818.

By region, the average IFPTO spans from a low of 0.05 to a high of 0.18, which is a very wide range. Again, the IFPTO does not appear consistent or useful because the IFPTO within each region has a very wide range. Because the range of IFPTO is very large for each region, similar ranges of total operations estimates, as detailed above, are found for each region.

Conclusion

Overall, the research team concludes that based on the study objectives and data, there are no practical and consistent IFPTOs found at the STAD airports that could then be used to estimate annual operations nationally or by climate region.

Table 3-3. Summary of the ratio of average GA IFR flight plans to total GA operations.

Region	Number of Airports	IFR/Total GA OPS Mean	IFPTO Range (Low)	IFPTO Range (High)
Central	33	0.1842	0.0134	0.4442
East North Central	13	0.1232	0.0572	0.3469
Northeast	28	0.1195	0.0400	0.3234
Northwest	8	0.0735	0.0174	0.1524
South	40	0.1306	0.0057	0.5495
Southeast	38	0.1656	0.0034	0.3759
Southwest	15	0.0818	0.0102	0.2007
West	27	0.0498	0.0057	0.1785
Overall	202	0.1298	0.0034	0.5495

Note: Alaska, Hawaii, and W. N. Central regions are removed due to having 0 or 1 airport in the region. One airport from the South is removed due to no IFR operations.

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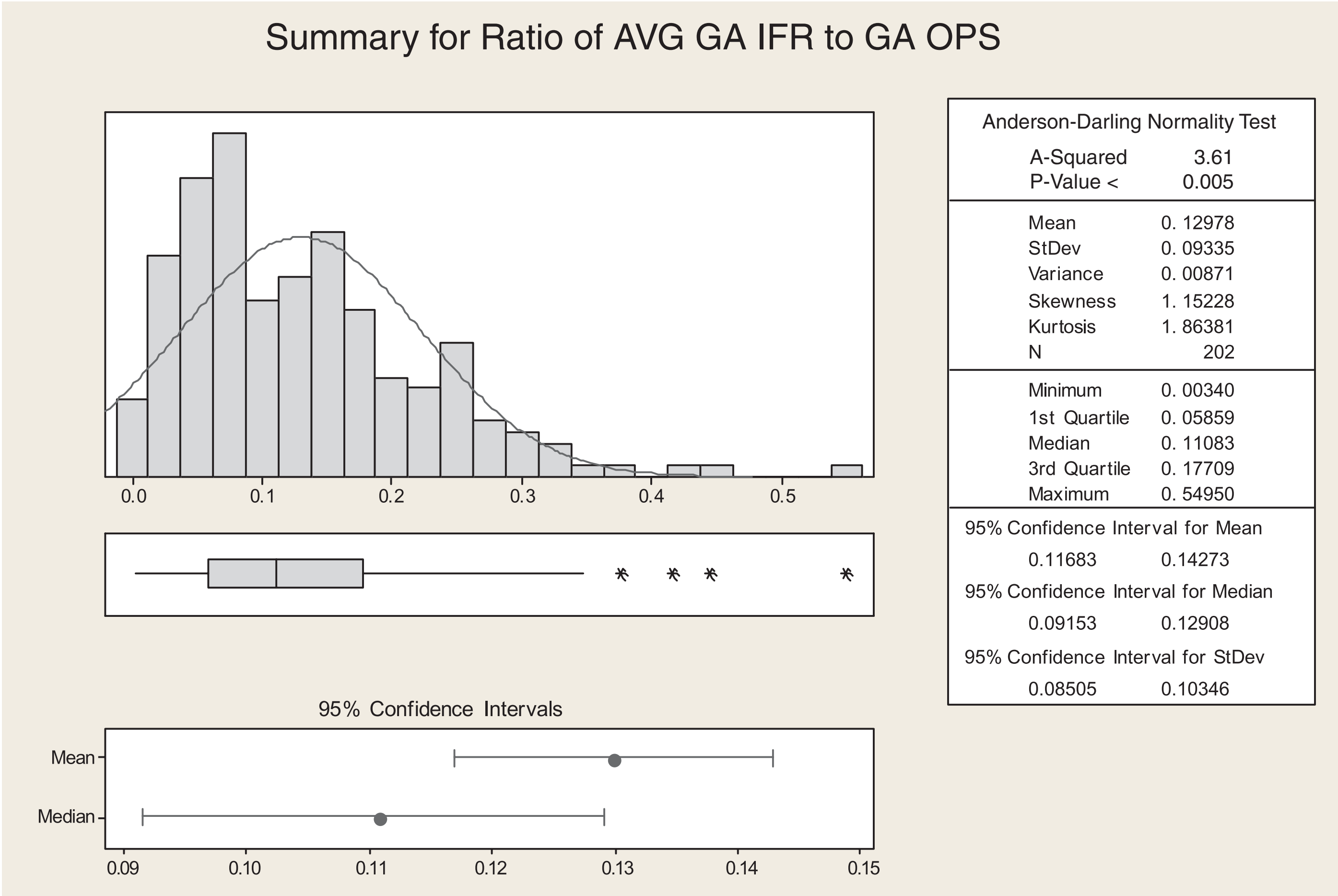

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Figure 3-1. Graphical summary for the IFR to total GA OPS for 202 towered airports.

Extrapolation Methods to Estimate Annual Airport Operations

The third method analyzed for estimating operations is expanding a sample count into an annual estimate. The counting of operations is time consuming. Sampling methods use statistical methods to reduce the amount of time needed for counting samples and still provide accurate estimates. Estimating annual operations using sampling methods is typically done either by statistical extrapolation of airport-specific sample counts or by extrapolation using monthly/seasonal adjustment factors developed from towered airports. The process and results of testing these two methods using data from small, towered airports are described below.

Statistical Extrapolation

When sample counts of aircraft operations are taken at an airport, the number and times of the samples will impact the results. Ideally, statistical sampling provides for a process where all weekly operation counts have an equal chance of being sampled because sampling relies on random choice. As a result, the sampling process ensures that the operations sampled are truly representative of the actual operations that occur throughout the year. This prevents certain factors from affecting the sample and skewing the resulting estimate (e.g., only sampling in good weather or sampling during a fly-in). The process of random sampling ensures that operations are sampled independently of the sampler's preferences and biases.

Since operations are estimated from samples and the end result may vary depending on the size of the sample and when the sample was taken (because airport activity will often vary according to day of week, weather, and season), this study attempted to analyze the accuracy of different sample sizes and times. The objective of this exercise was to examine the accuracy of extrapolating different sample sizes and times using the statistical methods in FAA-APO-85-7, *Statistical Sampling of Aircraft Operations at Non-Towered Airports.* Specifically, estimates of annual operations at small, towered airports (i.e., STAD) were calculated from different sample sizes and times using the methods in FAA-APO-85-7 and compared to the actual tower operations records.

This exercise included the following four elements:

1. Following FAA-APO-85-7, take random samples from 2010 FAA historical data for two randomly selected airports from the STAD in each climatic region for the following time periods.
   A. One week in each season (number of seasons depends on climate)
   B. Two weeks in each season (number of seasons depends on climate)
   C. One month in spring, summer, or fall
   D. One month in winter
   (Note: Four seasons of 13 weeks each were assumed for each year.)
2. Using forms and equations provided in Report No. FAA-APO-85-7, estimate annual operations for each airport for each of the four sample periods.
3. Compare estimated operations to actual operations for the year and determine variances.
4. Compare and present the various accuracy levels of different sampling sizes and times of year.

Analysis. From the STAD, two towered airports from each of eight NOAA climatic regions were randomly selected using a random numbers table. This selection resulted in 16 towered airports that were included in this analysis. These 16 airports are listed in Table 3-4. The West North Central region is excluded from this analysis because there are no

Table 3-4. Estimated total annual operations using statistical extrapolation for four sample sizes and times of actual weekly operations.

Airport 3-Letter Identifier (Climatic Region)	1 Week Per Season[1]	2 Weeks Per Season	1 Month (Winter) using Seasonal Distribution[1]	1 Month (Spring, Summer, or Fall) using Seasonal Distribution[1]	1 Month (Winter) (25%)[1]	1 Month (Spring, Summer, or Fall) (25%)[1]	Month Sampled	Actual
CPS (Central)	115,427	127,177	82,237	125,533	102,646	115,813	Fall	111,620
DPA (Central)	104,377	88,472	69,128	90,041	86,285	85,166	Spring	89,989
ANE (ENC)	68,978	82,833	59,084	95,807	73,747	90,620	Spring	79,603
MIC (ENC)	32,695	44,305	35,895	62,250	44,804	54,990	Summer	44,229
ASH (N. East)	72,644	85,816	44,466	69,107	55,502	63,756	Fall	74,111
RME (N. East)	38,922	48,734	41,076	53,235	51,270	47,027	Summer	47,790
PDT (West)	12,194	12,013	11,035	10,897	13,774	10,054	Fall	12,994
TIW (West)	43,914	51,514	39,486	57,986	49,286	54,847	Spring	53,960
FTW (South)	86,268	80,397	66,528	77,128	83,039	71,156	Fall	78,499
GLS (South)	27,599	33,687	22,787	40,154	28,443	35,472	Summer	31,652
HEF (Southeast)	81,744	100,170	65,652	109,057	81,946	90,339	Summer	92,394
OPF (Southeast)	100,763	99,433	82,794	103,351	103,342	97,756	Spring	98,708
BJC (Southwest)	113,048	114,955	88,248	88,248	110,150	110,150	Fall	120,363
HOB (Southwest)	15,639	14,701	13,574	19,940	16,943	18,860	Spring	16,637
CMA (West)	150,319	149,633	178,355	158,211	168,688	168,927	Spring	146,863
TOA (West)	118,716	105,617	98,010	118,442	122,334	104,630	Summer	106,438

1. See Appendix A for detailed information on how the sampling sizes and timeframes were structured.

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airports from that region in the dataset. This occurs because there are no airports from the West North Central region that meet the selection criteria for airports to be included in the dataset. Alaska and Hawaii were also excluded from this analysis because there is only one airport in each of those regions in the dataset.

Random samples of daily historic 2010 tower operations from the FAA for the four different timeframes presented were collected. Using these random samples from these four different timeframes, estimates of annual operations for each of the 16 airports were computed using the statistical methods presented in FAA-APO-85-7. The estimated annual operations were then compared to the actual annual operations to gauge reliability of using the four sample sizes and timeframes. (The sampling process for each of the four timeframes is described in detail in Appendix A.) In practice, actual error rates will be unknown for a non-towered airport, but a percent sampling error can be calculated which measures the precision of the annual operations estimate (e.g., 27,430 operations ±17.5%.).

Table 3-4 shows the annual operations estimated from the four sample sizes of operations data for each of the 16 small, towered airports selected. Table 3-5 shows the percent difference between each estimate of annual operations and the actual annual operations. At the bottom of the table, the highest and lowest percent differences are identified. The range between the highest and the lowest is also shown.

Table 3-5. Percent differences between statistical extrapolation of operations estimates and actual annual operations using four sample sizes and times.

Percent Difference from Annual Operations

Airport 3-Letter Identifier (Climatic Region)	1 Week Per Season	2 Weeks Per Season	1 Month (Winter) using Seasonal Distribution	1 Month (Spring, Summer, or Fall) using Seasonal Distribution	1 Month Winter (25%)	1 Month Spring, Summer, or Fall (25%)	Month Sampled	Actual
CPS (Central)	3.4%	13.9%	-26.3%	12.5%	-8.0%	3.8%	Fall	111,620
DPA (Central)	16.0%	-1.7%	-23.2%	0.1%	-4.1%	-5.4%	Spring	89,989
ANE (ENC)	-13.3%	4.1%	-25.8%	20.4%	-7.4%	13.8%	Spring	79,603
MIC (ENC)	-26.1%	0.2%	-18.8%	40.7%	1.3%	24.3%	Summer	44,229
ASH (N. East)	-2.0%	15.8%	-40.0%	-6.8%	-25.1%	-14.0%	Fall	74,111
RME (N. East)	-18.6%	2.0%	-14.0%	11.4%	7.3%	-1.6%	Summer	47,790
PDT (West)	-6.2%	-7.5%	-15.1%	-16.1%	6.0%	-22.6%	Fall	12,994
TIW (West)	-18.6%	-4.5%	-26.8%	7.5%	-8.7%	1.6%	Spring	53,960
FTW (South)	9.9%	2.4%	-15.2%	-1.7%	5.8%	-9.4%	Fall	78,499
GLS (South)	-12.8%	6.4%	-28.0%	26.9%	-10.1%	12.1%	Summer	31,652
HEF (Southeast)	-11.5%	8.4%	-28.9%	18.0%	-11.3%	-2.2%	Summer	92,394
OPF (Southeast)	2.1%	0.7%	-16.1%	4.7%	4.7%	-1.0%	Spring	98,708
BJC (Southwest)	-6.1%	-4.5%	-26.7%	-26.7%	-8.5%	-8.5%	Fall	120,363
HOB (Southwest)	-6.0%	-11.6%	-18.4%	19.9%	1.8%	13.4%	Spring	16,637
CMA (West)	2.4%	1.9%	21.4%	7.7%	14.9%	15.0%	Spring	146,863
TOA (West)	11.5%	-0.8%	-7.9%	11.3%	14.9%	-1.7%	Summer	106,438
High	16.0%	15.8%	21.4%	40.7%	14.9%	24.3%		
Low	-26.1%	-11.6%	-40.0%	-26.7%	-25.1%	-22.6%		
Range	42.1%	27.4%	61.4%	67.4%	40.0%	47.0%		

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Conclusion. Based on this analysis of the objectives and the dataset, the best statistical extrapolating method for these 16 airports is the 2 weeks per season because it provides the overall lowest variations from estimated to actual operations. This is consistent with the previous research results discussed in *ACRP Synthesis 4: Counting Aircraft Operations at Non-Towered Airports.*

Extrapolation Using Monthly/Seasonal Adjustment Factors from Towered Airports

Another method to extrapolate sampled operations to annual is the use of monthly or seasonal adjustment factors. The objective of this research exercise was to examine the accuracy of extrapolating annual operations using different sample sizes and times. This research exercise consisted of three elements:

- Calculate the percentage of operations that occur in each month for small, towered airports, and use these percentages to create monthly factors and seasonal factors for each region;
- Use those monthly and seasonal factors to extrapolate annual operations for two randomly selected airports in each NOAA Climatic Region; and
- Present and compare the accuracy levels of this extrapolation process using different sampling sizes and times of year.

Analysis. The analysis performed in this research task also included use of the STAD airports. The analysis included three steps:

1. Determine regional monthly and seasonal factors using all airports in the STAD by region.
2. Extrapolate annual operations using the monthly and seasonal factors from the STAD.
3. Compare actual operations to the estimates.

1. Determine regional monthly and seasonal factors using all airports in the STAD—As stated before, the first step in the analysis consisted of calculating monthly and seasonal factors for aircraft operations by region. To do this, the total operations for each month of 2010 were recorded for each airport in the STAD, and then monthly and seasonal factors for each region were calculated. Table 3-6 includes the monthly and seasonal factors for each region calculated from all airports in the STAD. (See Appendix A for detailed information on this analysis.)

   This analysis assumes all airports in a region have the same monthly and seasonal factors, that there are four seasons, and each season has 13 weeks. To maintain seasonal representation and to get all 12 months into four seasons for that calendar year, the seasons were identified as Winter (January–March), Spring (April–June), Summer (July–September), and Fall (October–December). In this way, the 2010 annual operations could be compared to the estimates

Table 3-6. Monthly and seasonal factors per region using all STAD airports.

Month	Northeast	Northwest	South	Southeast	Southwest	West	Central	East North Central
January	0.07	0.06	0.07	0.08	0.08	0.07	0.05	0.05
February	0.05	0.07	0.07	0.08	0.08	0.07	0.06	0.06
March	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09
April	0.09	0.09	0.09	0.10	0.08	0.08	0.09	0.08
May	0.10	0.10	0.09	0.09	0.08	0.09	0.09	0.09
June	0.10	0.10	0.09	0.08	0.09	0.09	0.09	0.10
July	0.10	0.10	0.09	0.08	0.08	0.09	0.10	0.12
August	0.10	0.10	0.09	0.08	0.08	0.09	0.10	0.10
September	0.08	0.09	0.09	0.08	0.09	0.09	0.09	0.09
October	0.08	0.08	0.09	0.09	0.09	0.08	0.10	0.09
November	0.08	0.05	0.08	0.08	0.08	0.08	0.08	0.07
December	0.06	0.05	0.07	0.07	0.08	0.07	0.06	0.05
Season								
Winter	0.20	0.22	0.23	0.24	0.25	0.23	0.20	0.20
Spring	0.28	0.29	0.27	0.27	0.25	0.26	0.27	0.27
Summer	0.28	0.30	0.26	0.23	0.25	0.27	0.29	0.31
Fall	0.23	0.19	0.24	0.25	0.24	0.23	0.24	0.22

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of annual operations developed using seasonal factors. It is important to note, however, that in practice, climatic conditions may vary widely between regions and even within each region.

2. Extrapolate annual operations using the monthly and seasonal factors from the STAD airports—The next steps for this research were to extrapolate annual operations using the monthly and seasonal factors developed in Table 3-6. Two STAD airports were randomly selected from each the eight regions (16 total) and samples from the following time periods were extrapolated into annual counts (using Table 3-6):
   A. One week in each season
   B. Two weeks in each season
   C. One month (either spring, summer, or fall)
   D. One month in winter

   The airport's actual operations and extrapolated operations were then compared to determine the accuracy of the time periods and monthly factors, which is outlined in the section below. (See Appendix A for detailed information on the sampling scenarios and airports.) Table 3-7 provides the results of the extrapolation.
3. Compare actual operations to the estimates—The final task included a comparison of the actual operations of the 16 test airports to the estimated operations. As shown in Table 3-7, the percent difference between each test airport's estimated annual operations and the actual annual operations were calculated. A summary of the percent differences between actual operation and estimated operations calculated with the monthly and seasonal factors is shown in Table 3-8, which includes the average, the average of the absolute values, the highest, the lowest, and the range for each of the four sampling scenarios.

As may be seen in Table 3-8, estimates made using the sampling scenario of two weeks per season provided an estimate closest to actual operations for the test airports, on average. The ranges for estimated operations for the sampling scenarios of 2 weeks per season and 1 month (spring, summer, or fall) were the closest to actual operations, in terms of range of the percent differences.

Conclusions. When extrapolating a sample count using monthly or seasonal factors, the sampling scenario of two weeks in each season is preferred by the research team. While the statistical analyses did not find a significant difference between the sampling scenarios (e.g., one week in each season, two weeks in each season, etc.) except for one month winter and one month spring, summer, or fall, there is a difference in the average percent difference and the range of percent differences that may be observed in Table 3-8. Additionally, Table 3-6 does show that there is a difference in the seasonal factors calculated for the seasons and this would result in a slight difference in the outcome if the season were comprised of different months. However, the statistical analysis is between what the computed and the actual operations are, and that range is so great that changing the months will not improve the outcome. The difference of the averages cannot be seen statistically because the variance is so large within the dataset for these airports. Of the four sampling scenarios, the two weeks in each season scenario has a combination of statistics reported that indicate preference over the other methods in this analysis. More airports would need to be tested in a future research project to determine if this preference is statistically significant for a larger variety of small, towered airports. (See Appendix A for more details on the statistical analysis performed.)

Overall Conclusions for Methods of Estimating Annual Airport Operations

Overall, the research team concludes that based on the study objectives and data, there were no practical and consistent OPBAs found or modeled at small, towered airports nationally or by climate region, even when considering the number of flight schools based at the airport. Therefore, the research team cannot recommend an OPBA for estimating annual operations at non-towered airports. Additionally, based on the data and study objectives, the research team concluded that there were no practical and consistent IFPTOs found at small, towered airports nationally or by climate region. Therefore, the research team cannot recommend an IFPTO for estimating annual operations at non-towered airports. Accordingly, to estimate an airport's operations, the team recommends taking a sample of actual operations and extrapolating annual operations from the sample. (See the following section for technology that can be used for sampling/counting aircraft operations).

When taking a sample count, the research team recommends sampling for two weeks in each season. This sample can be extrapolated by either a statistical extrapolation process or by use of seasonal/monthly adjustment factors developed from small, towered airports. The latter process assumes that the monthly and seasonal variations in traffic at small, towered airports are representative of non-towered airports. Based on this fact alone, the research team recommends using the statistical extrapolation process and performing sample counts for two weeks each season. This removes the need for additional data and the influences of outside forces on the extrapolation process.

The statistical extrapolation method may appear more mathematically difficult than the monthly/seasonal extrapolation method. However, step-by-step instructions, examples, and forms are available in FAA-APO-85-7, *Statistical Sampling of Aircraft Operations at Non-Towered Airports.* Appendix B includes an example of how this is done.

The following section describes different technology that can be used to sample operations.

Table 3-7. Estimates of annual operations using monthly/seasonal extrapolation and four sampling scenarios.

Airport	Region	1 Week each Season	2 Weeks each Season	1 Month Spring, Summer, or Fall	Season Selected	1 Month Winter	Month in Winter Selected	Actual Operations (OPSNET)	1 Week each Season	2 Weeks each Season	1 Month Spring, Summer, or Fall	1 Month Winter
CPS	Central	113,764	126,605	97,938	Fall	126,909	Feb.	111,620	2%	13%	-12%	14%
DPA	Central	101,692	82,865	72,858	Spring	72,360	Mar.	89,989	13%	-8%	-19%	-20%
ANE	East North Central	80,256	78,920	79,473	Spring	78,928	Feb. and Mar.	79,603	1%	-1%	0%	-1%
MIC	East North Central	30,029	40,558	35,739	Summer	45,481	Feb. and Mar.	44,229	-32%	-8%	-19%	3%
ASH	Northeast	68,659	82,627	57,111	Fall	61,563	Jan.	74,111	-7%	11%	-23%	-17%
RME	Northeast	49,531	47,908	35,943	Summer	73,128	Feb.	47,790	4%	0%	-25%	53%
PDT	West	12,106	12,440	14,016	Fall	13,034	Feb. and Mar.	12,994	-7%	-4%	8%	0%
TIW	West	48,266	48,837	42,199	Spring	54,603	Jan. and Feb.	53,960	-11%	-9%	-22%	1%
FTW	South	83,370	81,069	72,014	Fall	91,839	Feb.	78,499	6%	3%	-8%	17%
GLS	South	28,646	33,290	30,301	Summer	27,556	Feb. and Mar.	31,652	-9%	5%	-4%	-13%
HEF	Southeast	81,030	100,971	92,411	Summer	80,306	Feb. and Mar.	92,394	-12%	9%	0%	-13%
OPF	Southeast	94,524	96,819	82,483	Spring	101,658	Jan. and Feb.	98,708	-4%	-2%	-16%	3%
BJC	Southwest	115,364	113,461	114,742	Fall	106,536	Jan. and Feb.	120,363	-4%	-6%	-5%	-11%
HOB	Southwest	14,941	14,233	16,914	Spring	14,974	Feb. and Mar.	16,637	-10%	-14%	2%	-10%
CMA	West	151,100	148,393	165,637	Spring	174,536	Feb. and Mar.	146,863	3%	1%	13%	19%
TOA	West	118,025	79,103	85,326	Summer	115,623	Mar.	106,438	11%	-26%	-20%	9%

Note: Positive % differences indicate that the actual annual operations are larger than the estimated annual operations.
Negative % differences indicate that the actual annual operations are smaller than the estimated annual operations.
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Table 3-8. Summary of the percent difference between estimates using monthly/seasonal factors and OPSNET annual operations.

% Difference from OPSNET Annual Operations	1 Week each Season	2 Weeks each Season	1 Month Spring, Summer, or Fall	1 Month Winter
Average of real values	4%	2%	9%	2%
Average of absolute values	9%	8%	12%	13%
Highest	13%	13%	13%	53%
Lowest	-32%	-26%	-25%	-20%
Range	45%	39%	38%	73%

Aircraft Traffic Counters Evaluated

As detailed under Task 3 in Chapter 2, four different aircraft counting technologies were evaluated in a multiple case study using four airports. The technology included the following:

- AAC (portable acoustic counter).
- SMAC (portable acoustic counter).
- S/TC (portable camera with infrared night vision).
- Stationary VID with ADS-B transponder receiver (stationary).

Please refer to Chapter 2, Research Approach, for detailed information on the technology, the equipment evaluated, and the evaluation process. While the results of the analysis are detailed in the following pages, Table 3-9 below provides an overview of the findings.

Automated Acoustical Counter

Principle(s) of Operation and Intended Use

The AAC tested was a portable acoustic counter that operates by analyzing sounds for specific characteristics. (See

It is important to note that the goal of this research was not to develop a new method to count aircraft operations. Rather, it was to evaluate existing methods and technology for obtaining this information. These existing technologies and methods were identified in Tasks 1 and 2 in Chapter 2. The equipment tested represents typical technology used in the field at the time the evaluation program was developed. (New technological advances continue to result in new ways to count aircraft, and this report briefly discusses them and their potential in a section towards the end.)

It is important to note that all research has a certain level of uncertainty that limits the conclusions that can be drawn from it. This research is no different. While one may be able to effectively eliminate many of the factors that can affect the accuracy of a piece of equipment in a lab setting, this research did not attempt to do that. One of the primary goals of this project was to evaluate the equipment and methods as they are typically used in practice, and to use the equipment in the field tests in the same types of situations that it typically would be used, without eliminating natural factors that may affect the results. Natural factors include such things as wind direction, preferred runway, aircraft type and user experience, aircraft engine type, airport configuration, environmental influences, etc. Since these natural factors cannot be controlled in practice, no attempt was made to control or quantify them in this research. For example, on any given day, the wind may shift from favoring the use of one runway to favoring the use of another. One would not continually relocate counting equipment in practice based on wind direction, so this was not done during evaluation.

Since natural factors are so numerous and vary from airport to airport, they are virtually unquantifiable; therefore, the results shown here are only applicable to their respective test airports and should be considered case studies. The results in the field at other airports would likely be different depending on their unique characteristics. However, the information obtained from this research provides great value in understanding the limitations of the equipment and applying that understanding to its practical use in the field.

Table 3-9. Counting equipment evaluation matrix.

COUNTER	Automated Acoustical	Sound-Level Meter Acoustical	Security/Trail Camera	Video Image Detection (VID) Service Provider	VID Supplemental ADS-B Transponder Receiver Service Provider
Principle(s) of Operation	Embedded 32 bit, 72 megahertz, ARM 7 microprocessor, and system software.	Class 2 sound-level meter and analyzing software.	Passive infrared motion detection, nighttime infrared illuminator, and digital camera.	Electronic-based aircraft tracking using advanced video tracking that uses proprietary software, aircraft sensor systems, and digital camera equipment, and Aircraft Situation Display to Industry data.	Receiver collects information periodically broadcast from ADS-B equipped aircraft on their position obtained from satellite navigation.
Intended Use	Aircraft Counting.	Aircraft Counting.	Security, Wildlife Monitoring.	Automated landing fee collection, airport security, operations monitoring.	Air traffic and airport surface surveillance.
Computer Requirements	Typical Microsoft Windows-based computer with a USB port and Microsoft Excel® will allow the user to view the data.	Typical Microsoft Windows-based computer with a SD card slot and Microsoft Excel® will allow the user to view the data; ASNL software provided.	Typical Microsoft Windows-based computer with a SD card slot.	Typical Microsoft Windows-based computer with Internet access to view service provider website.	Typical Microsoft Windows-based computer with Internet access to view service provider website.
Event Recorded	Takeoff	Takeoff	Taxi to or from runway	Taxi to or from runway	Takeoff Landing Overflight
Typical Data Provided	Date Time	Date Time	Date Time Temperature Moon Phase Image	Date Time Image Aircraft N-Number Aircraft Make Aircraft Model Weight Design Group Wingspan	Date Time Aircraft N-Number
Ease of Portability	Easy - small, light, compact (weighs approx. 20 lbs.)	Easy - small, light, compact (weighs approx. 20 lbs.)	Easy - small, light, compact (camera weighs approx. 2 lbs.)	Although it is a standalone unit, it is not portable. Requires installation by technician.	Not portable. Requires installation by technician.
Durability	PVC housing for microphone and microprocessor and the solar panel were sturdy and durable. With the addition of a sealed bucket for housing the components and battery, the unit proved weather resistant.	Equipment is housed in a sturdy Pelican® case making it durable and weather resistant.	Camera is housed in a rugged weatherproof enclosure making it sturdy and durable.	Equipment is housed in sturdy all-weather casing which makes it durable.	The receiver used by the service provider failed during the test.
Ease of Installation and Airport Impacts	FAA Form 7460 filing required; Required to stay clear of RSA and TSA; Portable and self-contained unit resulted in easy installation.	FAA Form 7460 filing required; Required to stay clear of RSA and TSA; Portable and self-contained unit resulted in easy installation.	FAA Form 7460 filing required; Required to stay clear of RSA and TSA; Portable and self-contained unit resulted in easy installation.	FAA Form 7460 filing required; Required to stay clear of RSA and TSA; Self-contained unit, but not portable and requires installation by company technician.	Small unit and roof-top antenna. Portable, but requires installation by company technician.

Table 3-9. (Continued).

COUNTER	Automated Acoustical	Sound-Level Meter Acoustical	Security/Trail Camera	Video Image Detection (VID) Service Provider	VID Supplemental ADS-B Transponder Receiver Service Provider
Maintenance and Operation	Little maintenance required; solar panel was cleared of snow and grass removed from blocking microphone.	Required changing batteries on a frequent basis, replacing windscreen, clearing snow and grass from blocking microphone, calibrating sound-level meter.	Little maintenance required; solar panel was cleared of snow and grass removed from blocking lens.	No maintenance required other than ensuring cameras were not blocked by snow.	No maintenance required.
Ease of Data Retrieval	Simple - USB connection for direct upload to computer. When multiple counters are used on the same runway, manual removal of duplicate counts is required.	Simple - SD card slot for upload into computer. When multiple counters are used on the same runway, manual removal of duplicate counts is required.	Simple - SD card slot for upload into computer. Removal of duplicate pictures required for count because more than one picture is needed per motion detection to ensure tail number is viewable.	Simple - computer with internet service.	Simple - computer with Internet service.
Performance in Various Weather and Lighting Conditions	No impacts from lightning, thunder, or frigid temperatures encountered; Lighting issues not a factor.	No impacts from lightning or thunder encountered; Frigid temperatures deplete battery quickly and there is no solar panel charging option; Lighting issues not a factor.	No impacts from low/no lighting encountered; Frigid temperatures deplete battery in approx. 2 weeks, but addition of solar panel solves this; Night photos exceeded 70 ft. range limits of specifications.	No impacts from low/no lighting or frigid temperatures encountered.	The receiver used by the service provider failed during the test.
Service Contract Requirements	No contract required.	No contract required.	No contract required.	Contract required.	Contract required from service provider who writes specific algorithms to identify operations.
Cost	Approximately $4,800 each at time of test.	Approximately $4,800 each at time of test.	Approximately $1,000 each at time of test.	Approximately $31,000 for lease of two cameras and data analysis service for 7 months at time of test.	Approximately $5,000 for lease and data analysis for 7 months at time of test.
Best Accuracy Obtained During Case Studies	Multiple counters needed for longer runways; 92% using 3 counters on single 5,500 ft. runway.	Multiple counters needed for longer runways; 94% using 1 counter on single 2,800 ft. runway.	100% for taxis to and from runway at airport with simple configuration and centralized terminal area. All touch-and-goes missed. Error rate dependent on number of touch-and-goes at airport.	90% for taxis to and from the runway. All touch-and-goes missed. Error rate dependent on number of touch-and-goes at airport.	0% during testing. Unit failed during study. When working, it only identified 5 aircraft that were not already identified by the VID.
Other	Only counts takeoffs, which requires doubling to estimate operations; exceptionally quiet aircraft are missed; premise based on missed takeoffs (false negatives) being approximately offset by false positives.	Only counts takeoffs, which requires doubling to estimate operations; exceptionally quiet aircraft are missed; premise based on missed takeoffs (false negatives) being approximately offset by false positives.	Does not count touch-and-goes.	Does not count touch-and-goes	As of February 24, 2014, only 2% of the U.S. fleet had ADS-B out. (Lee-Lopez 2014) With this low equipage rate, ADS-B is not a viable solution to counting aircraft at this time.

Figure 3-2.) The system had an embedded 32, bit, 72 megahertz, ARM 7 microprocessor and system software that was programmed to detect the sounds associated with a takeoff. If the correct characteristics are detected, the microprocessor records the time, date, and acoustic characteristics of the event in its internal memory (Basil Barna). In order to conserve power, the AAC system tested is programmed to listen for activity at one second intervals. The system tested was first developed in the late 1990s for counting aircraft operations at secondary and backcountry airports (Basil Barna).

Figure 3-2. AAC.

Computer Requirements

A typical Microsoft Windows-based computer with a USB port and Microsoft Excel® will allow the user to view the data.

Data Provided

The AAC tested provided the user with the date and time of the event recorded, its loudness, and its duration in seconds. No individual aircraft characteristics were provided. Since the device only records takeoffs, the total events recorded were doubled to determine operations under the premise that for every takeoff there is a landing and vice versa.

Ease of Portability

The AAC was completely portable. It consisted of a polyvinyl chloride (PVC) plastic cylinder housing, four gigabytes of internal memory, 12-volt sealed lead-acid battery, 5-watt solar panel, and a USB 2.0 connection. The heaviest item was the battery. The sum total weight of the entire unit was approximately 20 pounds.

Although it was shipped in a durable Pelican® case, the case was not designed for use in the field. The initial installation included simply placing all the pieces on the ground (see center picture in Figure 3-2), but it quickly became apparent that this would not protect the equipment from the elements. The Indiana Department of Transportation, Office of Aviation staff, who utilize similar equipment, advised housing the unit inside a five-gallon bucket. Accordingly, a hole was cut into the side of the bucket a few inches from the base for the microphone, and everything but the solar panel was placed inside with the microphone extending through the hole. (See lower two pictures in Figure 3-2.) There were no user serviceable parts inside the unit. The microprocessor and microphone slide into the PVC weather protection sleeve. The solar panel and the electronics package power cable plug into the connector on the battery.

Durability

Despite its lack of housing for all the individual components, the AAC tested was designed for hardy use in outdoor conditions. The PVC housing for the microphone and microprocessor was sturdy and effectively sheltered the internal components. The maintenance-free battery ran the equipment continuously. The solar panel recharged the battery regardless of weather, but snow was cleared away at times during the winter. With the addition of the bucket for housing the components, the unit proved quite durable.

Ease of Installation and Airport Impacts

The FAA determined that any equipment installation on the airport, even if it were temporary and outside the runway safety area (RSA), required an FAA approval (through the filing of FAA Form 7460) in order to be in compliance with Title 14 of the CFR Part 77. In the case of this research, a Form 7460 airspace determination was filed for each location where the AAC was evaluated. Since the AAC is portable and it simply sits on the ground, there were no permanent installation requirements. As such, there was no impact to the airport infrastructure.

The user manual for the equipment instructed that it be located adjacent to the runway near a typical lift-off point, with the best location being one that maximized the sound of a takeoff and minimized all other sounds. It additionally instructed that the equipment be close to, but a safe distance away from the runway, typically 10 to 20 feet. However, to receive a non-objectionable airspace determination from the FAA on the Form 7460 submittal, the equipment had to be located outside of the RSA of the airports where it was evaluated. Typical RSAs at non-towered airports range from 120 feet wide (60 feet each side of runway centerline) to 500 feet wide (250 feet each side of runway centerline) depending on the size of the aircraft that use the airport. At this distance the equipment is generally farther away from the runway than it was designed to be. (Note: FAA AC 150/5300-13A, *Airport Design*, provides the width for all runway classifications in Appendix 7, Runway Design Standards Matrix. Although some are wider than 500 feet, the maximum width of the RSA where the acoustic equipment was tested was 500 feet.)

Maintenance and Operation

The AAC required little maintenance in the field. The solar panel provided ample power to recharge the battery during the seven months the equipment was deployed. The AAC had an internal battery for the internal clock that provided backup power when there was no external power. During the winter it was necessary to keep the cylinder unit clear of the snow so its listening device was not blocked. It was also necessary to occasionally cut tall grass away during the other seasons for the same reason. (See Figure 3-3.)

Ease of Data Retrieval

When the power harness was connected to the AAC, it automatically started collecting and storing data. When the USB cable was connected, it provided the user with an opportunity to synchronize clocks and then access the internal storage device that contained the comma-separated (i.e., cvs) data files. This generally worked fairly well, but to get any data from the AAC, this required the counter to be disconnected from power and then connected via USB to the computer. There was no optional memory card or flash drive downloading option. The power connection proved difficult to disconnect when the temperatures were below freezing and the user's fingers were cold. During the cold, the USB had intermittent problems connecting with the laptop computer for the data download, either due to the cold weather's impact on the computer or the USB connection. When more than one unit was used, the raw data had to be manually manipulated to remove duplicate counts. There was no automated feature for this, and the process was cumbersome, time consuming, and prone to human error. Once the sample is taken, the user has to extrapolate it into an annual count.

Figure 3-3. AAC deployed.

Performance in Various Weather and Lighting Conditions

The temperature reached a low of −1°F during the study and the AAC continued to work. While the laptop that was required for data download did not seem to work well in below freezing temperatures, the AAC appeared to be undaunted by it. After several weeks at below freezing, the AAC was still operating without interruption. Being acoustically activated, lighting conditions did not have any impact on the device. Additionally, thunder had no discernable impact on it either (i.e., thunder did not trigger it to record).

Service Contract Requirements

The AAC is a fully functioning, standalone unit that did not require any outside support. Once purchased, the user had the ability to operate the unit without the need of any type of service contract. The manufacturer was extremely helpful, personally delivering the device and teaching the researcher how to use it.

Cost Per Unit

The cost of the AAC will vary depending on when it is purchased since the prices of its composite pieces vary based on their respective markets. At the time of acquisition, two units were purchased for $4,800 each.

Accuracy Assessment

The AAC was evaluated at four airports in several different locations. Appendix D contains the airport diagrams for the four airports and the locations where the AAC equipment was located. The results are shown by airport in terms of percent error. This error is defined as the difference between the measured results and the actual results. The percent error is the ratio of the error to the actual results multiplied by 100. The smaller the error is, the higher the accuracy. When the percent error equals 100%, this means there were no correct measurements.

A percent error was computed for all takeoffs correctly recorded for each counter in each location. This did not include any false positives. (See the next paragraph for more information on false positives.) In the case of the acoustical counter, the equipment is only supposed to count takeoffs, and the manufacturers indicate that takeoffs are to be doubled to calculate operations. Therefore, a theoretical percent error could be computed for operations where the takeoffs correctly recorded by the counter are doubled and compared to the sum of the actual takeoffs and actual landings. However, this was not done because of systematic errors during observation that may skew the results. For example, if the majority of aircraft consistently takeoff in the morning for business purposes while visual observations are being recorded, but return after visual observations have stopped for the day, those landings are never recorded. The assumption is made here that for every takeoff there is a landing, so the percent error would be the same for takeoffs as for total operations if the sample is taken over a long enough period to compensate for the reciprocal operations that occurred before or after the counter was deployed.

In addition to the percent error for takeoffs and operations, percent errors were also calculated with false positives included. False positives can be a landing, a lawn mower, a taxi, or anything that is not a takeoff that triggers the counter to record. Since in actual use of the equipment, a user would be unable to remove any false positives, these were also tracked and percent errors computed for takeoffs with the false positives included.

The manufacturer designed the AAC so that "the analysis algorithm is set at a point where missed takeoffs (false negatives) are approximately offset by false positives" (Basil Barna). The manufacturer claimed that, "on balance the recorded count will be within 10% of the actual number of take offs" (Basil Barna).

Observed errors are presented on the following pages for each airport where the AAC was studied. The most important information gained from the research on the AAC is summarized below:

- There is no one level of accuracy that can be achieved with this equipment.
- It is not a simple "plug and play" type of device. Significant time must be taken to test that the counter(s) is located correctly, but there is not an easy way to get the data from the counter. It has to be completely powered down and opened up, which makes testing a location for accuracy time consuming.
- There is no one location that can be identified for the best performance (i.e., location is dependent on airport configuration, favored runway, and typical aircraft users).
- Multiple units may be needed to achieve an acceptable performance on many airports because the distance the equipment is located perpendicular to the rotation point (lift-off) of the aircraft impacts accuracy. And the use of multiple units requires removal of duplicate counts from the raw data, which also requires additional time.
- Airports with multiple/crossing runways prove extremely challenging to count accurately.
- FAA Forms 7460 were required to be filed for each piece of equipment, and to receive a determination of no hazard, the equipment had to be located outside of the RSA.

The longest study with the most sampling occurred at TYQ. This case study included visual observation over 15 days spanning seven months. Table 3-10 shows the overall results of this study. (Appendix D includes the airport diagram.)

Although the manual does not discuss the use of two counters, the length of TYQ's runway (5,500 feet) as compared to the length of the runways for which this counter was initially designed, and or tested on, suggested more than one counter may be needed. Therefore, the AAC was located at various positions along the runway to determine the best location, and to determine if more than one counter was needed to adequately cover the runway.

As described earlier, the user manual instructs for the equipment to be located adjacent to the runway near a typical lift-off (rotation) point, with the best location being one that maximizes the sound of a takeoff and minimizes all other sounds. It additionally instructs that the equipment be close to, but a safe distance away from the runway, typically 10 to 20 feet. Based on TYQ's RSA, all positions were required to be 250 feet from the runway centerline.

Initial field evaluation determined that the counters performed best when located as close as possible perpendicularly to the aircraft's rotation point, just as the manual instructs. As stated before, the manufacturer was extremely helpful and

Table 3-10. Overall results for Indianapolis Executive Airport—runway 18-36 (5,500 ft. × 100 ft.)

AAC Percent Error Result when Placed 250 ft. from Runway Centerline

Location A = 1800 ft. from Runway 18 End

Location B = 1800 ft. from Runway 36 End

Location C = Midpoint of Runway

LOCATION	A	B	C	A & B	A & C	B & C	A, B, & C
Percent Error for Takeoffs	42%	32%	35%	20%	28%	20%	17%
Percent Error for Takeoffs when False Positives are Included	35%	26%	27%	13%	20%	13%	8%
LOCATION	A	B	C				
Touch-and-Go Percent Error Rate by Counter	48%	48%	42%				

Prepared by: Woolpert, Inc.

INTERPRETATION EXAMPLE:

42% of the touch-and-goes were missed by the AAC in this location.

INTERPRETATION EXAMPLE:

A combination of counters positioned at locations A, B, and C produced operations counts 8% less than what actually occurred.

loaned a third counter for the case study to help find the optimal locations. When located in the middle of the runway, the counter almost always picked up at least half of the takeoffs, but many takeoffs were missed because the point of rotation was either too far beyond or behind the counter. Therefore, these positions were augmented by locations approximately halfway between the midpoint and the ends. The results were as expected. When Runway 18 was favored, the counters at midpoint and close to the end of Runway 36 produced better results than the one near the end of Runway 18 and vice versa. The results indicate that the use of three counters gives the best performance for a runway of this length. In most locations, however, the results from the counters were less than what was visually observed (i.e., the equipment undercounted operations). When false positives were included, the percent error decreased. The manufacturer's claim of ±10% was only achieved by the use of three counters on a runway of this length. And the claim is achieved by the inclusion of false positives. The number of false positives recorded was similar for each location, with the majority being from low approaches. Each counter rather equally missed touch-and-goes just under half the time. (See Tables 3-10 and 3-11.)

During the study, single engine piston (SEP) aircraft were the most often missed takeoffs, but they were also the most prevalent aircraft activity at the airport (see Table 3-12).

A case study on the AAC was also performed at EYE that included visual observations over three days. EYE's RSA allowed the counters to be located 75 feet from the runway centerline, which was 175 feet closer than at TYQ. EYE's runway is also 1,300 feet shorter than TYQ. Because of its length, the hypothesized location for the best results would be the midpoint of the runway (i.e., most aircraft would rotate within 2,100 feet). However, at this location the AAC missed the takeoffs more than half the time. (See Tables 3-13 and 3-14.)

Overall, the midpoint on EYE likely performed worse than the midpoint at TYQ because the runway is shorter and, unlike at TYQ, the majority of aircraft are beyond the midpoint when they reach rotation speed. Because the midpoint performed poorly, the counters were moved to the first and second thirds of the runway to determine if these locations better represented the typical takeoff points of aircraft. The results were similar to that of TYQ in that the counter performed worse when it was located on the third of the runway closest to end that the winds favored because the aircraft was well beyond that point at rotation speed. The opposite of this was also true in that the counter on the opposite end of the favored runway performed better. Additionally, when the middle counter results were added to the results of the more optimally located counter, the total error rate was less. However, unlike TYQ, the counters did not perform as well at EYE overall, but the testing time was significantly less.

During the EYE case study, SEP aircraft were the most often missed, but they were also the most prevalent aircraft activity at the airport. MEP aircraft were the next most often missed takeoffs. (See Table 3-15.)

Table 3-11. Favored runway results for Indianapolis Executive Airport—runway 18-36 (5,500 ft. × 100 ft.)

INTERPRETATION EXAMPLE:

A combination of counters positioned at locations A, B, and C produced operations counts 11% less than what actually occurred when Runway 18 was favored by the winds.

AAC Percent Error Result when Placed 250 ft. from Runway Centerline

Location A = 1,800 ft. from Runway 18End

Location B = 1,800 ft. from Runway 36 End

Location C = Midpoint of Runway

LOCATION	A	B	C	A & B	A & C	B & C	A, B, & C
Favored Runway = 18							
Percent Error for Takeoffs	54%	28%	43%	24%	37%	23%	21%
Percent Error for Takeoffs when False Positives are Included	47%	21%	34%	16%	28%	13%	11%
LOCATION	**A**	**B**	**C**	**A & B**	**A & C**	**B & C**	**A, B, & C**
Favored Runway = 36							
Percent Error for Takeoffs	19%	49%	16%	16%	11%	16%	11%
Percent Error for Takeoffs when False Positives are Included	16%	46%	14%	14%	8%	14%	8%
LOCATION	**A**	**B**	**C**	**A & B**	**A & C**	**B & C**	**A, B, & C**
Favored Runway = NA							
Percent Error for Takeoffs	0%	13%	13%	0%	0%	13%	0%
Percent Error for Takeoffs when False Positives are Included	**25%**	0%	13%	**25%**	**25%**	0%	**25%**

Note: A shaded cell with black text means the measured result was higher than the actual.
Prepared by: Woolpert, Inc.

Table 3-12. Indianapolis Executive Airport missed takeoff analysis.

AAC Missed % Takeoffs by Type

Type	Percent of Activity (takeoffs, landings, taxis, etc.)	Percent Takeoffs Missed
SEP	80.8%	85.1%
J	6.3%	5.3%
MEP	5.7%	4.3%
H	1.3%	3.2%
GYRO	0.8%	1.1%
METP	1.7%	1.1%
GV	2.3%	NA
SETP	1.1%	0.0%

INTERPRETATION EXAMPLE:

80.8% of the activity during the test was by SEP. 85.1% of the takeoffs missed by the AAC were performed by SEP.

SEP = single engine piston; MEP = multi-engine piston; J = jet; G = gyrocopter; GV = ground vehicle; SETP = single engine turbo prop; H = helicopter; METP = multi-engine turbo prop.

Prepared by: Woolpert, Inc.

Table 3-13. Overall results for Eagle Creek Airport—runway 3-21 (4,200 ft. × 75 ft.)

AAC Percent Error Results when Placed at Midpoint on Runway, 75 ft. from Centerline

	Midpoint
Percent Error for Takeoffs	63%
Percent Error for Takeoffs when False Positives are Included	63%
Touch-and-Go Percent Error Rate	75%

1,400 ft. from:	**RW 21**	**RW 3**
Percent Error for Takeoffs	41%	95%
Percent Error for Takeoffs when False Positives are Included	36%	95%
Touch-and-Go Percent Error Rate	67%	100%

Prepared by Woolpert, Inc.

Table 3-14. Results by favored runway Eagle Creek Airport—runway 3-21 (4,200 ft. × 75 ft.)

AAC Percent Error Results when Placed 75 ft. from Runway Centerline

1400 ft. from 21 End and Midpoint	**RW 21**	**Midpoint**	**Combined**
Favored Runway = 3			
Percent Error for Takeoffs	41%	68%	36%
Percent Error for Takeoffs when False Positives are Included	36%	68%	32%

Midpoint and 1400 ft. from Runway 3 End	**Midpoint**	**RW 3**	**Combined**
Favored Runway = 3			
Percent Error for Takeoffs	57%	95%	57%
Percent Error for Takeoffs when False Positives are Included	57%	95%	57%

Prepared by: Woolpert, Inc.

Table 3-15. Eagle Creek Airpark missed takeoff analysis.

AAC Missed % Takeoffs by Type

Type	**Percent of Activity (takeoffs, landings, taxis, etc.)**	**Percent Takeoffs Missed**
SEP	77.0	85
MEP	9.3	10
J	6.2	2
METP	2.5	2
G	0.0	0
SETP	0.0	0
H	0.6	0
GV	4.3	NA

SEP = single engine piston; MEP = multi-engine piston; J = jet; G = gyrocopter; GV = ground vehicle; SETP = single engine turbo prop; H = helicopter; METP = multi-engine turbo prop.

Prepared by: Woolpert, Inc.

A case study on the AAC was also completed at I42. This airport was chosen for its shorter runway and narrower RSA, which would allow for the counter to be located closer to the runway. Additionally, this airport better represented the type of runway the AAC was designed for when developed. This study included visual observations over three days. Because of the short length of the runway, the vast majority of takeoffs occurred near the midpoint, so the AAC was located at the midpoint at varying distance from the centerline. (See Appendix D for airport diagrams.) Because of the low traffic during the first day of testing, a local aircraft and pilot were enlisted to perform several hours of takeoffs, landings, and touch-and-goes during the second and third days. While this was the type of runway the AAC was designed for, it did not perform well. However, this may be because the majority of the operations were performed in a Cessna 172G with a Continental O-300 SER 145HP engine. (See Table 3-16.) The counters seemed to function better when moved farther from the runway centerline, which is contrary to expectations, but the Continental O-300 SER significantly affected the results. It did not seem to matter where the aircraft with this engine was when it rotated; the AAC registered it less than 10% of the time. And at 1,400 feet from either end, the units were optimally located for catching the rotation point. During testing, this aircraft consistently lifted off the ground within approximately 200 feet of a point perpendicular of the counter location, but was not detected. The manufacture's website states that the AAC may miss a takeoff if the aircraft is exceptionally quiet, and this proved true at I42. When the Continental O-300 was removed from the evaluation, two of the AAC units caught every takeoff.

Because three counters were located side-by-side at I42, this case study also looked at the consistency of the AAC. Although all three counters were the same, they did not perform exactly the same. However, none recorded any false positives, so the error rates were the same with and without false positives. Like TYQ, the AAC undercounted operations.

Finally, a case study of the AAC was performed at LAF to determine its effectiveness on an airport with crossing runways. The study included visual observation over six days. The RSA for LAF's primary runway required the equipment to be located no closer than 250 feet from the centerline of Runway 10-28 and 150 feet from the centerline of Runway 5-23. When the study was developed, two counters were thought to be needed because of the two runways, and various locations were approved by the FAA based on the need for two counters. However, two counters were insufficient to track traffic on this airport. In all probability, even three counters would likely not perform sufficiently if the winds did not consistently favor their locations. Table 3-17 shows the overall percent errors for each location studied while Table 3-18 shows the results based on favored runway. Note that a shaded cell with black text means that the measured result was higher than was visually observed (i.e., the counter over counted).

The locations that produced the overall best results before false positives were included were a combination of B, C, and D. These results were the best because these locations had no error rate when Runway 10 was favored. They also had the lowest error rate when Runway 5 was favored, but when Runway 28 was favored, they did not correctly record any takeoffs. When false positives were included into the mix, a combination of locations C and D produced the best results overall. Either

Table 3-16. Paoli Municipal Airport—runway 2-20 (2800 ft. × 50 ft.)

AAC Percent Error Results from Side-by-Side Evaluation at Midpoint of Runway at Varying Distances from Runway Centerline	Continental O-300 SER Comprising 81% of Activity		
Locations A = 50 ft. from Runway Centerline	**AAC#1**	**AAC#2**	**AAC#3**
Percent Error for Takeoffs	81%	94%	94%
Percent Error for Takeoffs when False Positives are Included	81%	94%	94%
Locations B = 75 ft. from Runway Centerline			
Percent Error for Takeoffs	83%	87%	87%
Percent Error for Takeoffs when False Positives are Included	83%	87%	87%
Locations B = 125 ft. from Runway Centerline			
Percent Error for Takeoffs	71%	43%	43%
Percent Error for Takeoffs when False Positives are Included	71%	43%	43%

Note: If an engine larger/louder than the Continental O-300 SER was in the aircraft with the majority of operations performed during this test, the equipment would likely have performed better.

Prepared by: Woolpert, Inc.

Table 3-17. Overall results for Purdue University Airport—two runways (runway 10-28: 2,793 ft. × 50 ft.; runway 5-23: 6,600 ft. × 150 ft.)

AAC Percent Error Results

Location A = Midpoint of Runway 10-28, 250 ft. from Centerline
Location B = 2,000 ft. from Runway 28 End, 250 ft. from Centerline
Location C = 1,200 ft. from Runway 23 End, 150 ft. from Centerline
Location D = Midpoint of Runway 10-28, 250 ft. from Centerline; 1,000 ft. from Runway 5-23 Centerline

LOCATION	A	B	C	A & B	A & C	B & C	A, B, & C
Percent Error for Takeoffs	53%	82%	99%	49%	53%	82%	49%
Percent Error for Takeoffs when False Positives are Included	44%	78%	99%	38%	44%	78%	38%
LOCATION	**B**	**C**	**D**	**B & C**	**B & D**	**C & D**	**B, C, & D**
Percent Error for Takeoffs	52%	41%	70%	36%	52%	28%	21%
Percent Error for Takeoffs when False Positives are Included	30%	25%	52%	9%	27%	5%	**6%**

Note: A shaded cell with black text means the measured result was higher than the actual.

Prepared by Woolpert, Inc.

Table 3-18. Results by favored runway for Purdue University Airport—two runways (runway 10-28: 2,793 ft. × 50 ft.; Runway 5-23: 6,600 ft. × 150 ft.)

AAC Percent Error Results

Location A = Midpoint of Runway 10-28, 250 ft. from Centerline
Location B = 2,000 ft. from Runway 28 End, 250 ft. from Centerline
Location C = 1,200 ft. from Runway 23 End, 150 ft. from Centerline
Location D = Midpoint of Runway 10-28, 250 ft. from Centerline; 1,000 ft. from Runway 5-23 Centerline

LOCATION	A	B	C	A & B	A & C	B & C	A, B, & C
Favored Runway = 23							
Percent Error for Takeoffs	93%	93%	96%	93%	93%	93%	93%
Percent Error for Takeoffs when False Positives are Included	85%	89%	96%	85%	85%	89%	85%
Favored Runway = 28							
Percent Error for Takeoffs	33%	77%	100%	27%	33%	77%	27%
Percent Error for Takeoffs when False Positives are Included	23%	73%	100%	13%	23%	73%	13%
LOCATION	**B**	**C**	**D**	**B & C**	**B & D**	**C & D**	**B, C, & D**
Favored Runway = 28							
Percent Error for Takeoffs	100%	100%	100%	100%	100%	100%	100%
Percent Error for Takeoffs when False Positives are Included	100%	100%	100%	100%	100%	100%	100%
Favored Runway = 5							
Percent Error for Takeoffs	69%	32%	88%	22%	69%	25%	22%
Percent Error for Takeoffs when False Positives are Included	59%	24%	81%	8%	54%	12%	7%
Favored Runway = 10							
Percent Error for Takeoffs	15%	40%	35%	40%	15%	13%	0%
Percent Error for Takeoffs when False Positives are Included	**30%**	8%	**3%**	**13%**	**33%**	**30%**	**53%**

Prepared by: Woolpert, Inc.

Table 3-19. Purdue University Airport missed takeoff analysis.

AAC Missed % Takeoffs by Type

Type	Percent of Activity (takeoffs, landings, taxis, etc.)	Percent Takeoffs Missed
SEP	95.3	95.2
MEP	4.3	3.0
J	0.0	1.8
GV	0.0	0.0
GYRO	0.0	0.0
SETP	0.0	0.0
H	0.4	0.0
METP	0.0	NA

SEP = single engine piston; MEP = multi-engine piston; J = jet;
G = gyrocopter; GV = ground vehicle; SETP = single engine turbo prop;
H = helicopter; METP = multi-engine turbo prop.
Prepared by: Woolpert, Inc.

Table 3-20. Mower evaluation—AAC side-by-side results.

	AAC#1	AAC#2	AAC#3
False Positives			
Mower 60 ft. in front of counter	0	0	0
Mower 55 ft. in front of counter	0	0	0
Mower 50 ft. in front of counter	0	0	0
Mower 45 ft. in front of counter	0	0	0
Mower 40 ft. in front of counter	0	0	0
Mower 35 ft. in front of counter	0	0	0
Mower 30 ft. in front of counter	0	0	0
Mower 25 ft. in front of counter	0	0	0
Mower 20 ft. in front of counter	0	0	0
Mower 15 ft. in front of counter	1	1	0
Mower 10 ft. in front of counter	1	1	1
Mower 5 ft. in front of counter	1	1	1
Mower 5 ft. behind counter	1	1	1
Mower 10 ft. behind counter	1	1	1
Mower 15 ft. behind counter	1	1	1
Total False Positives	6	6	5

Prepared by: Woolpert, Inc.

locations C and D or locations B, C, and D achieved the manufacturer's claimed error rate, and while it may be tempting to assume they would achieve this universally, these locations only work if the winds favor them, which they did over the six days the units were tested. Again, when the winds did not favor them, error rates of 100% were reached. In summary, while error rates of 5% and 6% were obtained with three counters, it was only because the equipment had counted non-takeoffs 20% of the time and the winds favored their positions during the evaluation. Adding more counters may reduce the percent error rate, but that would likely only be because they were counting more false positives. The more counters included, the more confusing it is to analyze the results and remove double or triple counts, and the process becomes increasingly susceptible to human error.

During the study, SEP aircraft were again the most often missed takeoffs, but they were also the most prevalent aircraft activity at the airport. MEP aircraft were the next most often missed takeoffs. (See Table 3-19.)

Mowing is a major function at all airports, and mowers have the potential to trigger an acoustically activated aircraft traffic counter. Since no mowing was done during any of the evaluations, a separate mowing study was performed to determine if and when a mower might trigger the counter. The results of the mower evaluation revealed that two of the three counters were triggered by the mower at 15 feet in front of the unit. All three were triggered by the mower at five-foot increments from 10 feet in front of to 15 feet behind the units. (See Table 3-20.)

Sound-Level Meter Acoustical Counter

Principle(s) of Operation and Intended Use

The SMAC tested included a sound-level meter and special software package for identifying aircraft takeoffs. (See Figure 3-4.) Paired together, the system is supposed to record sounds and then differentiate those that are takeoffs from other events. Once the appropriate parameters are set on the sound meter, data are recorded and stored on the instrument's memory card inside the unit. The software then identifies which noise events were aircraft takeoffs. These data are then sent to an electronic database.

Since the system works with a Class 2 sound-level meter, it can also be used to measure noise in general.

Figure 3-4. SMAC.

Computer System Requirements

A typical Microsoft Windows®-based computer with a SD memory card reader and Microsoft Excel® is needed to access and manipulate the data. The ASNL software reads the files from the SD card, computes the number of takeoffs, and then saves the results in an electronic database

Data Provided

The SMAC provided the user with the date and time of the event (i.e., takeoff) recorded and its Lmax (maximum sound pressure level). No individual aircraft characteristics were provided. Since the device only recorded takeoffs, the total events recorded were doubled to determine operations under the premise that for every takeoff there is a landing and vice versa.

Ease of Portability

The SMAC was completely portable. The noise meter and two 6-volt sealed lead-acid batteries were housed in a durable case with a sum total weight of the unit of 20 pounds. To move the unit, one only needed to simply grab the handle of the case and go.

Durability

The SMAC came housed in a sturdy Pelican® case. The only component exposed to the elements was the microphone, which was covered by a foam wind screen. This wind screen disappeared a few times during the study, likely the result of a curious animal.

Ease of Installation and Airport Impacts

As indicated previously, the FAA determined that any equipment installation on the airport, even if it were temporary and outside the RSA, required an FAA approval (through the filing of an FAA Form 7460) in order to be in compliance with Title 14 of the CFR Part 77. In the case of this research, a Form 7460 airspace determination was needed for each location where the SMAC was evaluated. Since the SMAC was portable and simply sat on the ground, there were no permanent installation requirements. As such, there was no impact to the airport infrastructure.

Several parameters have to be set on the sound meter before it could be left to count. Close attention was required when setting these or the system would not work correctly. To interpret the data from the SMAC, software was required, which was provided by the manufacturer. Initial installations were unsuccessful and required assistance from a company representative.

The user manual instructs for the equipment to be located close to the runway. To receive a non-objectionable airspace determination from the FAA on the Form 7460 submittal, the equipment had to be located outside of the RSA of the airports where it was evaluated. Typical RSAs at non-towered airports range from 120 feet wide (60 feet each side of runway centerline) to 500 feet wide (250 feet each side of runway centerline), depending on the size of the aircraft that use the airport. (Note: FAA AC 150/5300-13A, *Airport Design*, provides the width for all runway classifications in Appendix 7, Runway Design Standards Matrix. Although some are wider than 500 feet, the maximum width of the RSA where the acoustic equipment was tested was 500 feet.) This distance was generally farther away than the equipment was designed for use.

Maintenance and Operation

The SMAC required very little maintenance in the field outside of changing the batteries. Since there was no external power source and the unit did not come with a solar power option, the batteries required changing every one to two weeks, if not sooner in cold weather. During the winter, the external microphone stayed above the snow so it was never blocked. However, tall grass had to occasionally be cut away during the other seasons so as not to interfere with the microphone. A snow fall of approximately 15 inches or more would begin to block the microphone. Additionally, the microphone can become a bird perch, which makes occasionally changing the wind screen necessary due to the buildup of bird droppings. (See Figure 3-5.)

Ease of Data Retrieval

Except for opening the case, data retrieval from the SMAC was fairly easy. While the units are well protected from the weather, this protection proves cumbersome when the batteries need to be changed or data downloaded. To open the case, the mounting system for the microphone had to be removed. This required removing a small wing nut that was in tight

Figure 3-5. SMAC deployed.

quarters, which was almost impossible to do while wearing gloves. When the wing nut is removed with cold fingers, it can easily be dropped and lost in the snow.

The data was stored on a SD card inside the sound meter. This card was easily swapped out with an empty card in the field and then uploaded to the computer once in the office out of the elements. The software included with the equipment outputs the total number of events recorded. It then follows a statistical process for estimating annual operations from the sample, which is virtually the same statistical process that was described earlier. More specifically, the software read the files from the sound-level meter, saved the results in a Microsoft Excel® file, and used Visual Basic for Applications (VBA) macros in an Excel® template to produce a final report for the estimated annual operations.

Performance in Various Weather and Lighting Conditions

The temperature reached a low of −1°F during the study, and while the SMAC worked in these temperatures, the batteries only lasted a few days before they had to be replaced. Being acoustically activated, lighting conditions did not have any impact on the device. Also, thunder did not have any discernable impact on it either (i.e., it did not trigger the unit to record).

Service Contract Requirements

The SMAC was a fully functioning, standalone unit that did not require any outside support. Once purchased, the unit can be operated without the need of any type of service contract.

Cost Per Unit

The cost of the SMAC will vary depending on when it is purchased since the prices of its composite pieces vary based on their respective markets. At the time of acquisition, two units were purchased for approximately $4,800 each.

Accuracy Assessment

The longest study with the most sampling occurred at TYQ. This case study included visual observations over 14 days spanning seven months. Table 3-21 shows the overall results of this study. (Appendix D includes the airport diagrams.) The most important information gained from the research on the SMAC is similar to what was gained on the ACC. It is summarized below:

- There is no one level of accuracy that can be achieved with this equipment.
- It is not a simple "plug and play" type of device. Significant time must be taken to test that the counter(s) are located correctly, but there is not an easy way to determine if the equipment counted the aircraft without opening up the case.
- There is no one location that can be identified for the best performance (i.e., location is dependent on airport configuration, favored runway, and typical aircraft users).
- Multiple units may be needed to achieve an acceptable performance on many airports because the distance the equipment is located perpendicular to the rotation point (lift-off) of the aircraft impacts accuracy. And the use of multiple units requires removal of duplicate counts from the raw data, which also requires additional time.
- Airports with multiple/crossing runways prove extremely challenging to count accurately.
- FAA Forms 7460 were required to be filed for each piece of equipment, and to receive a determination of no hazard, the equipment had to be located outside of the RSA.

The user manual for the SMAC did not indicate the need for more than one counter for a runway, but experience with the AAC indicated more may be needed, as proved to be the case. As described earlier, the user manual instructs for the equipment to be located close to the runway where it will detect the most takeoffs. Based on TYQ's RSA, all positions were required to be 250 feet from the runway centerline. Two SMAC counters were located side-by-side at the midpoint of the runway where they produced percent error rates of 87% each. When false positives were added in at this location, the error rate

Table 3-21. Midpoint results for Indianapolis Executive Airport—runway 18-36 (5,500 ft. × 100 ft.)

SMAC Percent Error when Placed 250 ft. from Runway Centerline		
SIDE-BY-SIDE EVALUATION AT RUNWAY MIDPOINT	**SMAC#1**	**SMAC#2**
Favored Runway = 18		
Percent Error for Takeoffs	87%	87%
Percent Error for Takeoffs when False Positives are Included	83%	83%

Prepared by: Woolpert, Inc.

Table 3-22. Overall results on first and last third of runway at Indianapolis Executive Airport—runway 18-36 (5,500 ft. × 100 ft.)

SMAC Percent Error when Placed 250 ft. from Runway Centerline

Location A = 1800 ft. from Runway 18 End

Location B = 1800 ft. from Runway 36 End

LOCATION	A	B	A & B
Percent Error for Takeoffs	72%	82%	63%
Percent Error for Takeoffs when False Positives are Included	61%	68%	38%

Prepared by: Woolpert, Inc.

was reduced to 83% for both counters. (See Table 3-21.) This evaluation seemed to indicate that the majority of aircraft were not rotating close enough to the counter's location perpendicular to the runway to trigger the equipment. They were either rotating too far before or after the counter.

The user manual states that the parameters used in the SMAC were established based on an accuracy study performed in November and December 2005 at Tipton Airport in Maryland. (Note: It does not state the accuracy obtained from that study.) It is important to note that the runway at Tipton is 3,000 feet in length, which is 2,500 feet shorter than the one at TYQ. This is obviously a contributing factor to why the SMAC did not perform as well at the midpoint of TYQ's runway. Both units did, however, perform the same.

The two SMAC counters were also placed at 1,800 feet from each runway end. At these locations they produced better results—error rates of 72% and 82%. (See Table 3-22.) As was the case with the AAC, two units performed better than one because they were able to "listen" over more area. When both counters were used together at these two locations, they produced a combined percent error rate of 63%, which was almost cut in half—38%—when false positives were included. (See Table 3-23 for results based on favored runway.) This evaluation seemed to conclude that many landings were being counted in these locations, but close review of the data revealed that the false positives were mostly comprised of non-events (i.e., NOT a landing or a low approach). There were instances when one counter recorded several events just a minute or two apart. While this happened on both counters, it did not happen at the same time. One might conclude that the counters were triggered by birds sitting on the wind screen as these screens were covered in bird droppings. Regardless, the counter was cutting its error rate almost in half not by counting engine noise like it was supposed to, but by counting mostly non-events.

Although three counters were not used in the case study, deploying counters at all three locations would reduce the error rate. However, the counter was clearly missing a significant number of takeoffs this distance from the runway centerline.

A case study on the SMAC was also performed at EYE that included visual observations over three days. EYE's RSA

Table 3-23. Results by favored runway at first and last third of runway—Indianapolis Executive Airport—runway 18-36 (5,500 ft. × 100 ft.)

SMAC Percent Error when Placed 250 ft. from Runway Centerline

Location A = 1800 ft. from Runway 18 End

Location B = 1800 ft. from Runway 36 End

LOCATION	A	B	A & B
Favored Runway = 18			
Percent Error for Takeoffs	81%	84%	74%
Percent Error for Takeoffs when False Positives are Included	68%	71%	48%
LOCATION	**A**	**B**	**A & B**
Favored Runway = 36			
Percent Error for Takeoffs	49%	81%	38%
Percent Error for Takeoffs when False Positives are Included	46%	62%	16%

Prepared by: Woolpert, Inc.

Table 3-24. Overall results Eagle Creek Airport—runway 3-21 (4,200 ft. × 75 ft.)

SMAC Percent Error when Placed at Midpoint on Runway, 75 ft. from Centerline

	Midpoint
Percent Error for Takeoffs	30%
Percent Error for Takeoffs when False Positives are Included	16%
Percent Error Rate for Touch-and-Goes	63%

SMAC Percent Error when Placed at First and Last Third of Runway, 75 ft. from Centerline

1,400 Ft. from:	RW 21	RW 3
Percent Error for Takeoffs	27%	24%
Percent Error for Takeoffs when False Positives are Included	**4%**	24%
Percent Error Rate for Touch-and-Goes	33%	80%

Note: A shaded cell with black text means the measured result was higher than the actual.

Prepared by: Woolpert, Inc.

allowed the counters to be located 75 feet from the runway centerline, which was 175 feet closer than at TYQ. EYE's runway is also 1,300 feet shorter than TYQ, so different locations were selected to determine if the runway could be counted with one counter, or if more would be needed. Based on the instruction manual, the hypothesized location for the best results would be the midpoint of the runway. At this location the SMAC caught takeoffs 70% of the time (30% error rate), and when the false positives were included, the percent error rate was reduced to 16%. (See Table 3-24.) The runway was also divided into thirds and counters located in the middle of the first and last third to see if the performance was better. (See Table 3-25 for results based on favored runway.) The error rate on the counter on the third closest to Runway 21 was significantly reduced when false positives were included. At closer look, the SMAC counted a few taxis, landings, and low approaches at this location, which reduced its error in undercount of takeoffs. Therefore, two counters on this runway would likely produce viable results when the winds changed to either's favor. Although using three counters would likely produce a lower error rate, there would be a significant number of takeoffs that could be double counted. As described earlier, editing the raw data is time consuming, cumbersome, and prone to human error. The false positives at EYE were equally distributed between landings, low approaches, and non-events.

During the EYE case study, SEP aircraft were the only aircraft missed, but like the other airports, they were also the most prevalent aircraft activity. (See Table 3-26.)

A case study on the SMAC was also completed at I42. Its smaller RSA allowed for the counter to be located closer to

Table 3-25. Results by favored runway for Eagle Creek Airport—runway 3-21 (4,200 ft. × 75 ft.)

SMAC Percent Error when Placed 75 ft. from Runway Centerline

Locations 1400 ft. from Runway 21 End and Runway Midpoint	RW 21	Midpoint	Combined
Favored Runway = 3			
Percent Error for Takeoffs	30%	30%	17%
Percent Error for Takeoffs when False Positives are Included	4%	9%	**13%**
Locations Runway Midpoint and 1400 ft. from Runway 3 End	**Midpoint**	**RW 3**	**Combined**
Favored Runway = 3			
Percent Error for Takeoffs	29%	24%	19%
Percent Error for Takeoffs when False Positives are Included	24%	24%	14%

Note: A shaded cell with black text means the measured result was higher than the actual.

Prepared by: Woolpert, Inc.

Table 3-26. Eagle Creek Airpark missed takeoff analysis.

SMAC Missed Percent Takeoffs by Type

Type	Percent of Activity (takeoffs, landings, taxis, etc.)	Percent Takeoffs Missed
SEP	80.4%	100%
MEP	9.3%	0.0%
J	6.2%	0.0%
GV	2.5%	NA
GYRO	0.0%	0.0%
SETP	0.0%	0.0%
H	0.6%	0.0%
METP	4.3%	0.0%

SEP = single engine piston; MEP = multi-engine piston; J = jet; G = gyrocopter; GV = ground vehicle; SETP = single engine turbo prop; H = helicopter; METP = multi-engine turbo prop.

Prepared by: Woolpert, Inc.

the runway. This airport better represented the type of runway at which the SMAC was initially tested in Maryland. This study included visual observation over three days. Because of the length of the runway and the type of aircraft that typically use the facility, the vast majority of takeoffs occurred near the midpoint, so the SMAC was located at the midpoint at varying distance from the centerline. A local aircraft and pilot were enlisted to perform several hours of takeoffs, landings, and touch-and-goes. The SMAC performed better the closer it was to the runway. However, its consistency was questionable in this side-by-side evaluation. While one counter had only a 6% error rate at 50 feet from the runway, the other was 0% (both with the false positives added into the total). As was the case with the AAC, the SMAC had trouble picking up the Cessna 172G with a Continental 0-300 SER 145HP engine. At 75 feet and greater from the runway centerline, it missed this aircraft the vast majority of the time. (See Table 3-27.)

Finally, a case study of the SMAC was performed at LAF to determine its effectiveness on an airport with multiple runways. The study included visual observations over six days. The RSA for LAF's primary runway required the equipment to be located no closer than 250 feet from the centerline of Runway 10-28 and 150 feet from the centerline of Runway 5-23. When the study was developed, two counters were thought to be needed because of the two runways, and various locations were approved by the FAA based on the need for two counters and manufacturer instructions. However, two counters were insufficient to track traffic on this airport. (See Table 3-28.) Locations B and C provided the best results because the winds favored Runway 5 and Runway 10 during much of those evaluations, but the error rate was still greater than 50%. (See Table 3-29.) It is difficult to assume that even three counters would have produced much better results. When multiple runways are involved, it becomes increasingly difficult to locate a counter in a location that will optimally serve one runway without resulting in substantial false positives from the other runway. And, with a runway as long as those at LAF, even two counters could not adequately count one runway.

Mowing is a major function at all airports, and mowers have the potential to trigger an acoustically activated aircraft traffic counter. Since no mowing was done during any of the study, a separate mowing evaluation was performed to determine if and when a mower might trigger the SMAC. The results of the mower study revealed that a mower has the

Table 3-27. Paoli Municipal Airport—runway 2-20 (2800 ft. × 50 ft.)

SMAC Percent Error Results from Side-by-Side Evaluation at Midpoint of Runway at

Varying Distances from Runway Centerline	*Continental O-300 SER Comprising 81% of Activity*	
Locations A = 50 ft. from Runway Centerline	**SMAC#1**	**SMAC#2**
Percent Error for Takeoffs	13%	6%
Percent Error for Takeoffs when False Positives are Included	**6%**	0%
Locations B = 75 ft. from Runway Centerline		
Percent Error for Takeoffs	79%	79%
Percent Error for Takeoffs when False Positives are Included	79%	79%
Locations C = 125 ft. from Runway Centerline		
Percent Error for Takeoffs	71%	43%
Percent Error for Takeoffs when False Positives are Included	57%	14%

Note: If an engine larger/louder than the Continental O-300 SER was in the aircraft with the majority of operations, the equipment may have performed better at further distances from the runway centerline.
Note: A shaded cell with black text means the measured result was higher than the actual.

Prepared by: Woolpert, Inc.

Table 3-28. Overall results for Purdue University Airport—two runways (runway 10-28: 2,793 ft. × 50 ft.; Runway 5-23: 6,600 ft. × 150 ft.)

SMAC Percent Error

Location A = Midpoint of Runway 10-28, 250 ft. from Centerline

Location B = 2,000 ft. from Runway 28 End, 250 ft. from Centerline

Location C = 1,200 ft. from Runway 23 End, 150 ft. from Centerline

LOCATION	A	C	A & C
Percent Error for Takeoffs	94%	99%	94%
Percent Error for Takeoffs when False Positives are Included	91%	99%	91%
LOCATION	**B**	**C**	**B & C**
Percent Error for Takeoffs	95%	72%	69%
Percent Error for Takeoffs when False Positives are Included	94%	71%	65%

Prepared by: Woolpert, Inc.

potential to trigger the counter when within 5–10 feet of the equipment. (See Table 3-30.)

Security/Trail Camera

Principle(s) of Operation and Intended Use

The S/TC tested was a digital camera with a passive infrared (PIR) motion detector and a nighttime infrared illuminator all contained in a weather-resistant case. (See Figure 3-6.) The particular camera tested was originally designed for covert operations, such as security and wildlife study. The system operated on 12 AA batteries or from a 12 volt power pack charged by a solar panel. Images were stored on an internal memory card. The optional additional solar panel was added for long-term use in cold weather and a cable box was added to the system to make it less conspicuous. Neither were required. The motion detector consisted of two horizontal detection bands each divided into six zones. The manual indicated the camera will capture movement up to 100 feet

Table 3-29. Results by favored runway Purdue University Airport—two runways (runway 10-28: 2,793 ft. × 50 ft.; Runway 5-23: 6,600 ft. × 150 ft.)

SMAC Percent Error

Location A = Midpoint of Runway 10-28, 250 ft. from Centerline

Location B = 2,000 ft. from Runway 28 End, 250 ft. from Centerline

Location C = 1,200 ft. from Runway 23 End, 150 ft. from Centerline

LOCATION	A	B	A & C
Favored Runway = 23			
Percent Error for Takeoffs	89%	96%	89%
Percent Error for Takeoffs when False Positives are Included	81%	96%	81%
Favored Runway = 28			
Percent Error for Takeoffs	96%	100%	96%
Percent Error for Takeoffs when False Positives are Included	96%	100%	96%
LOCATION	**B**	**C**	**B & C**
Favored Runway = 28			
Percent Error for Takeoffs	90%	100%	90%
Percent Error for Takeoffs when False Positives are Included	90%	100%	90%
Favored Runway = 5			
Percent Error for Takeoffs	97%	61%	58%
Percent Error for Takeoffs when False Positives are Included	95%	59%	54%
Favored Runway = 10			
Percent Error for Takeoffs	95%	83%	80%
Percent Error for Takeoffs when False Positives are Included	93%	80%	75%

Prepared by: Woolpert, Inc.

Table 3-30. Mower evaluation—SMAC side-by-side results.

	SMAC#1	SMAC#2
False Positives		
Mower 60 ft. in front of counter	0	0
Mower 55 ft. in front of counter	0	0
Mower 50 ft. in front of counter	0	0
Mower 45 ft. in front of counter	0	0
Mower 40 ft. in front of counter	0	0
Mower 35 ft. in front of counter	0	0
Mower 30 ft. in front of counter	0	0
Mower 25 ft. in front of counter	0	0
Mower 20 ft. in front of counter	0	0
Mower 15 ft. in front of counter	0	0
Mower 10 ft. in front of counter	1	0
Mower 5 ft. in front of counter	1	1
Mower 5 ft. behind counter	0	1
Mower 10 ft. behind counter	0	0
Mower 15 ft. behind counter	0	0
Total False Positives	2	2

Prepared by: Woolpert, Inc.

Figure 3-6. S/TC.

Figure 3-7. Wildlife caught on the S/TC.

away in daylight and 70 feet at night. These claims were either met or exceeded during our evaluation.

Since the camera works based on passive infrared motion detection, it is designed to record any heat-based movement. Accordingly, it works well in detecting wildlife, one use for which it was initially designed. With the FAA requirements for wildlife hazard assessments and mitigation programs, cameras like these may be useful for wildlife monitoring on an airport. (See Figure 3-7.)

Computer System Requirements

A typical computer with a memory card reader is needed to access the images in the S/TC. Images can be uploaded to a computer with any standard image viewing software, or the viewing software provided with the equipment. The S/TC could accept memory cards up to 32 GB.

Data Provided

The S/TC evaluated produced images with a resolution of 1080p or 3.1mp with a .jpg file extension. The images included a date, time, temperature, and moon phase stamp and the image number in the series (e.g., 1 of 3). The images could be viewed with any standard image viewing software. The viewing software that came with the camera provided an easy way to catalog photos by camera location and aircraft type. The database could then be searched for all aircraft of a certain type, make, or model. The database was only limited by how much information the user tagged to each photo. Although the software did appear useful for cataloging, there did not appear to be a tally feature, so the aircraft had to be manually counted. It did allow for the creation of a video of the pictures, which, in addition to just appearing impressive, can provide a quick overview of the type of traffic an airport experiences. Figure 3-8a and Figure 3-8b show some of the images captured by the S/TC.

Figure 3-8a. Typical image captured by the S/TC.

Ease of Portability

The S/TC was completely portable. The camera could be mounted on a stake or inside the optional cable box. The solar panel did not come with a mounting pole, so one had to be fabricated. Outside of fabricating a mounting pole, both were easy to deploy and relocate where needed. (See Figure 3-6.) The weight of the camera was approximately two pounds. The solar panel and sealed battery weighed approximately 20 pounds.

Durability

The S/TC came housed in a sturdy all-weather case. The unit continued to work even when dropped and performed continuously for the duration of the study with the addition of the solar panel.

Ease of Installation and Airport Impacts

As indicated previously, the FAA determined that any equipment installation on the airport, even if it were temporary and outside the RSA, required FAA approval (through the filing of FAA Form 7460) in order to be in compliance with Title 14 of the CFR Part 77. In the case of this research, a Form 7460 airspace determination was needed for each location where the S/TC was evaluated. Since the S/TC is portable, self-contained, and simply sticks into the ground on a short stake, there were no permanent installation requirements. As such, there was no impact to the airport infrastructure.

Since there was no way to monitor the runway without stationing cameras to adequately cover every location where an aircraft might touch down or takeoff, the cameras were located on the taxiways/taxilanes to capture aircraft entering or exiting the runway. This was the same concept that was used for pneumatic counters in the past.

The S/TC cameras were evaluated at four different airports at varying distances from the taxiway/taxilane centerlines. To receive a non-objectionable airspace determination from the FAA on the Form 7460 submittal, the equipment had to be located outside of the TSA of the airports where it was tested. Typical TSAs at non-towered airports range from 49 feet wide (24.5 feet each side of centerline) to 118 feet wide (59 feet each side of centerline) depending on the size of the aircraft that use the airport. (Note: FAA AC 150/5300-13A, *Airport Design*, provides the width for all taxiway classifications in Chapter, Taxiway and Taxilane Design. The maximum distance the S/TC was tested was 300 feet, which is farther than its purported range of 100 feet.)

Several parameters had to be set on the camera before it could be left to monitor movement. Since the camera records images based on infrared movement, close attention was required when setting these or the camera may not capture pictures at night well enough to read the aircraft registration numbers. Additionally, the number of pictures taken per event had to be enough to ensure the aircraft registration number was in view during at least one of the pictures.

The user manual instructed that the equipment should be located within 100 feet of the desired subject in the daytime and 70 feet at night. The field of view was approximately 40°, but a walk test was encouraged with each installation to ensure the unit was working.

Maintenance and Operation

The S/TC required very little maintenance in the field once the solar panels were installed. The location where the unit was installed was maintained by airport ground crew, so no additional mowing or grass removal was needed to ensure the lens was not blocked. The solar panel had to be cleared of snow a few times to ensure the battery was charging.

Ease of Data Retrieval

Except for opening the cable box, data retrieval from the S/TC was fairly easy. While the units were inconspicuous with the cable box, taking the top on and off to get to the camera was cumbersome. The data was stored on a SD card inside the camera, which was easily swapped out with an empty card in the field and then uploaded to the computer once in the office out of the elements. However, determining if a particular target was captured required removing the card and reading it via a computer. This makes initial testing of a location time consuming.

Performance in Various Weather and Lighting Conditions

The temperature reached a low of −1°F during the durability testing and while the S/TC worked in these temperatures,

Figure 3-8b. Images captured by the S/TC.

the cameras functioned in the field only up to about two weeks with lithium batteries at below freezing temperatures. Without any type of rechargeable lithium AA batteries sold on the market, battery usage would be expensive in cold weather because each camera requires 12 batteries. Rechargeable NI-CAD batteries can likely be used in milder temperatures, but they do not last long in the cold. The manual purports that NiMH batteries will operate at temperatures down to –20°F and lithium batteries will operate to –40°F. Temperatures never reached this cold, but lithium batteries were initially used anyway; however, solar panels were eventually added. The units worked continuously with the addition of the panels. Occasionally snow was cleared to ensure charging.

The S/TC purports a range of 70 feet at night, which was easily obtained. While the default settings to the camera generally produced good results, some exceptions were made. A 15-second trigger quiet period reduced the number of times the same aircraft event was recorded and the fast shutter night mode provided clearer night images. (See Figure 3-9 for low light images.) There were times when the aircraft registration number was not visible or the picture not clear enough (due to the low light, fog, rain, or snow) to determine the N-number. However, the aircraft types (e.g., SEP, jet, etc.) was almost always discernable in one of the three to five images taken per event (the user has the option to set the number of images the camera captures once it is triggered.)

Surprisingly, besides taxing aircraft, the cameras also caught a few helicopters approaching and departing (see Figure 3-8b) even though the helicopters seemed to be outside of the sensor's maximum distance. However, like the VID equipment, they are not capable of capturing touch-and-goes without stationing some undetermined number of cameras to cover every location where an aircraft could touch down. Accordingly, the cameras have to be strategically located along taxiways and some type of touch-and-go factor would have to be determined and added to the total to achieve an accurate estimate. The night evaluation performed resulted in 95% accuracy of taxis recorded.

Figure 3-9. S/TC images.

Service Contract Requirements

The S/TC was a fully functioning, standalone unit that did not require any outside support. Once purchased, the unit could be operated without the need of any type of service contract.

Cost Per Unit

The cost of the S/TC will vary depending on when it is purchased since the prices of its composite pieces vary based on their respective markets. At the time of acquisition, the units cost $550 each. The cable box was $150 and the additional solar panel was $300.

Accuracy Assessment

The S/TC was evaluated at four different airports. The longest study with the most sampling occurred at TYQ where they were located approximately 70 feet from the taxiway centerline. The test included visual observation over 13 days spanning seven months. This study used two cameras purchased from the manufacturer and installed at the two locations where aircraft have to pass to enter or exit the airport terminal area. (Note: For an airport with more entry and exits points, additional cameras would be needed.) Table 3-31 shows the overall results of this study.

The user manual for the S/TC tested indicated that an object with a different temperature than the ambient temperature had to move into, or out of at least one of six motion detection zones in one of two detection bands, and that a walk test should be performed. While the walk test worked with the north facing

Table 3-31. Indianapolis Executive Airport.

S/TC Percent Error Results	
Location A - North Facing	
Percent Error for Taxis Recorded	43%
Location B - South Facing	
Percent Error for Taxis Recorded	0%
Missed Taxis Analysis	
Single Engine Piston (SEP)	92.5%
Multi-Engine Turbo Prop (METP)	5.0%
Gyro	2.5%
The north facing camera was located on the taxiway that leads directly to the end of Runway 18. The SEP often taxied at slower speeds past this camera because it led directly to the runway end.	
Touch-and-Go Activity	
15% of the activity observed during the study were touch-and-goes, which are not recorded by the S/TC. Therefore, the error rate for actual operations would be 15% greater than taxis' recorded results.	

Prepared by: Woolpert, Inc.

camera, it did not always catch aircraft. The instruction manual also indicated that as the ambient temperature approaches the temperature of the subject, the strength of the signal decreases and the range of the camera is reduced. Another point made in the manual was that if a subject is moving very slowly, it will not always trigger the motion sensor.

The cameras generally worked well when they were set on high sensitivity except for SEP aircraft on the north facing camera. The north facing camera was on the taxiway that led directly to the end of Runway 18. The SEP aircraft often taxied at lower speeds past this camera as they entered the runway, as compared to the south camera on the taxiway that led to the parallel taxiway. The misses on the north camera appeared to increase at temperatures around 70°F and 80°F versus those at temperatures at 30°F and 40°F. However, the south camera did not have this same problem. In fact, the south camera did not miss a target. Finally, with 21% of TYQ's operations from touch-and-goes during the study period, the percent error ratio for recording operations for the equipment as a whole would increase by this amount.

A short-term study was also performed on the S/TC at EYE for a day. Units were located at 75 feet and 100 feet from one taxiway centerline and all aircraft that passed that location were observed and recorded. The two cameras detected every aircraft that passed in front of them. (See Table 3-32.)

A short-term study was also performed on the S/TC at I42. The units were located at 35 feet, 50 feet, 75 feet, and 100 feet from one taxiway centerline at the only entrance to and from the terminal area and all aircraft that passed that location were observed and recorded. The cameras detected every aircraft that passed in front of them at this airport as well. (See Table 3-33.)

A short-term study was also performed on the S/TC at LAF. At this airport the S/TC was attached to the terminal building to track every aircraft that taxied across the apron. While the apron is approximately 300 feet wide, most of the aircraft taxied in the middle third and were detected by the camera. At this location, the S/TC missed 19% of the aircraft that taxied in front of it. (See Table 3-34.)

Table 3-32. Eagle Creek Airport—runway 3-21.

S/TC Percent Error Results from Side-by-Side Evaluation at Varying Distances from Taxiway Centerline	
Location A = 75 ft. from Runway Centerline	
Percent Error for Taxis Recorded	0%
Location B = 100 ft. from Runway Centerline	
Percent Error for Taxis Recorded	0%

Prepared by: Woolpert, Inc.

Table 3-33. Paoli Municipal Airport—single runway.

S/TC Camera Results from Side-by-Side Evaluation at Varying Distances from Taxiway Centerline	
Location A = 35 ft. from Runway Centerline	
Percent Error for Taxis Recorded	0%
Location B = 50 ft. from Runway Centerline	
Percent Error for Taxis Recorded	0%
Location C = 75 ft. from Runway Centerline	
Percent Error for Taxis Recorded	0%
Location D = 100 ft. from Runway Centerline	
Percent Error for Taxis Recorded	0%
Touch-and-Go Activity	
18% of the activity observed during this study were touch-and-goes, which are not recorded by the S/TC.	

Prepared by: Woolpert, Inc.

Table 3-34. Purdue University Airport.

S/TC Percent Error Results across 300 ft. Wide Apron	
Attached to Terminal Building	
Percent Error for Taxis Recorded	19%

Note: This location is 200 feet wider than the purported detection range of the S/TC. While many aircraft taxied outside the reported range, several were still detected by the camera.

Prepared by: Woolpert, Inc.

VID System/ADS-B Transponder Receiver

Principle(s) of Operation and Intended Use

The VID system tested was originally developed to automate the billing process for landing fees. The spinoff use of the VID is aircraft traffic counting and airport security. The VID system tested combines electronic-based tracking and advanced video tracking. (See Figure 3-10.) One source of the electronic tracking is the FAA near real-time traffic data from the National Airspace System (NAS) known as the Aircraft Situation Display to Industry (ASDI). The data includes information on aircraft operating in radar control. The video tracking data comes from VID equipment (i.e., cameras) installed at a particular airport. For the system tested, the VID software and aircraft sensor systems worked together to provide a more comprehensive depiction of airport activity than either technology alone would. The ASDI feed provided detailed aircraft data or the VID equipment captured an image of the aircraft registration number as it passed by the camera and the service provider analyzed the image. From both feeds, the VID system service provider delivered detailed information about the aircraft via a web portal. To augment the capability of its video image detection system, the VID system tested also included a simple transponder receiver programmed to detect ADS-B and Mode S transmissions.

Figure 3-10. VID system.

Computer System Requirements

A typical computer with Internet access was used for viewing the VID web portal and downloading data.

Data Provided

Detailed information about the aircraft was made available on a web portal, including the date, time, aircraft registration number, call sign if applicable, activity type (e.g., arrival, departure), aircraft make and model designator (e.g., LJ40 for Lear Jet 40), maximum landing weight, runway design group, wingspan group, aircraft type (e.g., jet, piston), operator's information (e.g., contact name, telephone number, address), and source of the data (e.g., camera, ASDI, or transponder receiver). Detailed activity reports could be produced that included all the activity by a particular aircraft, all arrivals, all departures, etc.

Ease of Portability

The VID system tested was not permanently installed, but was also not portable. Professional installation from the service provider was required.

Durability

The VID camera system was housed in a sturdy all-weather casing. The unit worked continuously for the duration of the study. The transponder receiver failed, but when it did work, it provided very little useful information that was not already provided from another source.

Ease of Installation and Airport Impacts

Since there was no way to monitor the runway without stationing a massive number of cameras along its parallel axis to adequately cover every location where an aircraft might touch down, the more common practice is to locate cameras on the taxiways/taxilanes to capture aircraft entering or exiting the runway. As indicated previously, the FAA determined that any equipment installation on the airport, even if it were temporary and outside the TSA, required an FAA approval (through the filing of an FAA Form 7460) in order to be in compliance with Title 14 of the CFR Part 77. In the case of this research, a Form 7460 airspace determination was needed for the locations where the VID was installed. To receive a non-objectionable airspace determination from the FAA on the Form 7460 submittal, the equipment had to be located outside of the TSA of the airport where it was evaluated. Typical TSAs at non-towered airports range from 49 feet wide (24.5 feet each side of runway centerline) to 118 feet wide (59 feet each side of runway centerline) depending on the size of the aircraft that use the airport. (Note: FAA AC 150/5300-13A, *Airport Design*, provides the width for all taxiway classifications in Chapter 4, Taxiway and Taxilane Design. The maximum distance the VID equipment was studied was approximately 100 feet.) Two units were located outside of the TYQ taxiway safety areas of the only two taxiway entrance points to the parallel taxiway. All aircraft entering or exiting the runway for takeoff or landing must pass one of these points.

The VID equipment itself (outside of the web portal and antenna) was self-contained and free standing with no external power supply needed. No digging was required, so there was no worry of hitting lighting or navigational aid (NAVAID) cabling. The system included cameras—each with two batteries, a solar panel, a night illumination source, and an Ethernet bridge antenna to communicate with the cameras. In the field, the cameras were located outside of the taxiway object free areas and pointed towards the taxiways exiting the runway and the parallel taxiway. The cameras initially had trouble distinguishing aircraft movement converging on and diverging from the camera, so adjustments were made to the viewing field so that aircraft passed through the field of view from left to right and vice versa.

Maintenance and Operation

The VID system required no maintenance from the user and none from the vendor during the evaluation program. As stated earlier, the transponder receiver equipment failed during the study.

Ease of Data Retrieval

The web portal to the activity data was straight forward and easy to navigate. Reports and data could be easily downloaded into CSV files that could be imported into an electronic database.

Performance in Various Weather and Lighting Conditions

The temperature reached a low of −1°F during the durability testing and the VID performed without impact. There were times when the aircraft registration number was not visible or the picture was not clear enough for the VID service provider to return the detailed aircraft information. However, the type of aircraft (e.g., SEP, jet, etc.) was still provided. Figure 3-11 shows the typical images recorded from the VID. The night evaluation performed resulted in 94% accuracy of taxis recorded.

Figure 3-11. VID images.

The ADS-B transponder receiver did not perform as expected. During actual visual observations, the transponder receiver had a 100% error rate. The unit did, however, record some aircraft. Over the time the receiver resided at the airport, a total of 20 events were recorded by five different aircraft. However, these same aircraft operated at the airport 129 times over the course of the study. When the VID service provider first provided a quote for the equipment, the company had a supported ADS-B transponder receiver product. However, by the time of the equipment installation, the company was no longer using the transponder equipment because of the low number of the U.S. aircraft fleet actually equipped with ADS-B. Because of this and other technical and software algorithm problems, the transponder receiver never performed well and provided no information that was not already provided by the VID or the ASDI data.

Service Contract Requirements

The VID system required a contract. The equipment was not purchased outright, but installed for an initial deployment price and the information was provided through the web portal with a contract, which typically covered a year. If the contract is not renewed, the equipment is removed.

Cost Per Unit

The cost of the VID system tested over the seven months of this study, which included two cameras and a transponder receiver unit, totaled $36,000. Without the transponder receiver, the seven month cost was $31,000. The cost of the

ADS-B Technology

By January 1, 2020, all aircraft must be equipped with ADS-B out technology to operate in the following airspace:

1. Class A, B, and C.
2. Class E airspace within the 48 contiguous states and the District of Columbia at and above 10,000 feet mean sea level (MSL), excluding the airspace at and below 2,500 feet above the surface.
3. Class E airspace at and above 3,000 feet MSL over the Gulf of Mexico from the coastline of the United States out to 12 nautical miles.
4. Around those airports identified in 14 CFR part 91, Appendix D

(FAA 2014)

According to the *FAA Aerospace Forecast Fiscal Years 2013-2033*, the U.S. fleet is made up of 7,024 commercial aircraft and 217,533 general aviation aircraft. As of February 24, 2014, only 3,391 aircraft had ADS-B out (FAA), which would equate to less than 2% of the U.S. fleet. With this low equipage rate, ADS-B is not a viable solution to counting aircraft at non-towered airports at this time, but may prove useful closer to the 2020 deadline. (Lee-Lopez 2014)

Table 3-35. Indianapolis Executive Airport.

VID Percent Error Results	
North Facing	
Percent Error for Taxis Recorded	17%
South Facing	
Percent Error for Taxis Recorded	10%
Missed Taxis Analysis	
Single Engine Piston (SEP)	78.3%
Multi-Engine Turbo Prop (METP)	8.7%
Jet (J)	13.0%

Notes: The north facing camera was located on the taxiway that lead directly to the end of Runway 18. The SEP often taxied at higher speeds past this camera because they did not have to slow down for a turn as compared to the south camera.

ASDI Feed	
Operations reported on ASDI feed that were not on camera	5
Non-events recorded by ASDI (aircraft was not detected visually)	2

Touch-and-Go Activity
21% of the activity observed during the study were touch-and-goes, which are not recorded by VID or ASDI.
Error rate for actual operations would be 21% greater than taxis recorded results.

Transponder Receiver	
Percent Error for Operations Recorded by Transponder Receiver	100%

Prepared by: Woolpert, Inc.

service will vary from airport to airport depending on the airport's configuration and the number of cameras needed to adequately cover runway entrance and exit points.

Accuracy Assessment

The VID equipment study at TYQ included visual observations for 16 days spanning seven months. Like the S/TC, the VID equipment was located at the only two entrance and exit points from the terminal area. (See Appendix D for a diagram of the equipment locations.) Table 3-35 shows the overall results of this study. Like the S/TC, the VID camera facing north had a greater error rate, which may be a result of the same reasons. Also like the S/TC, the VID equipment cannot count touch-and-goes. With 21% of TYQ's operations from touch-and-goes during the study period, the percent error ratio for the equipment as a whole would increase by this amount. While the ADS-B transponder receiver equipment had the potential to count touch-and-goes with the correct computer algorithms programmed, the unit did not perform well because of the very low number of aircraft equipped with ADS-B technology and because of technical issues with the equipment and software itself. When the receiver and associated algorithms did work, it only identified five aircraft that were not already identified by the cameras. During visual observations it had a 100% error rate for operations recorded. As with all the other equipment, the most missed aircraft were SEP aircraft, but they were also the most prevalent operations at the airport.

CHAPTER 4

Conclusions and Suggested Research

Conclusions

Methods for estimating aircraft operations and methods for counting airport operations were studied under this research. The conclusions are presented separately for each of these research items.

Methods for Estimating Annual Airport Operations

The methods for estimating annual operations that were studied included the following:

1. Multiplying based aircraft by an estimated number of OPBA,
2. Applying a ratio of IFR flight plans filed to total operations (IFPTO), and
3. Extrapolating from a sample count.

OPBA

A study was performed to determine if there is a consistent number(s) of OPBA that occur at STAD that could then be applied to non-towered airports. (For a discussion on the STAD database, please refer to Chapter 2 of this report.) The study also considered if the OPBA varied by climate or population and if having a flight school(s) affected this number. Initial analysis revealed that an extremely large range of OPBAs exist for the STAD airports overall and by region, and practical use of any averages would not produce confident results. With this in mind, the research team attempted to actually model total OPBA through regression analysis to determine if an equation could be produced that offered better results. While several different approaches were taken, including full model regression, reduced model regression, and transformation of the data, either the statistical assumptions necessary for the regression to be valid could not be met or there were extremely large variations from actual to estimated operations on the test airports. Accordingly, based on the variables studied there does not appear to be a consistent number of OPBA at small, towered airports that can be applied to non-towered airports for use in estimating airport operations nationally or by climate region. Consequently, the research team cannot recommend using a standard number(s) of OPBA for estimating annual airport operations. While FAA Order 5090.3C *Field Formulation of the National Plan of Integrated Airport Systems (NPIAS)* gives general guidance on OPBA values, applying those values in practice with any degree of confidence is difficult at best. Continuing research in this area may be tempting, but this study and historical research has shown that developing statistical models for total operations may be more descriptive than models for OPBA.

IFPTO

An analysis was performed on small, towered airports to determine if a consistent ratio of IFPTO occur at these facilities that could then be applied to non-towered airports. Overall, the research team concludes that based on the study objectives and data, there are no practical and consistent IFPTOs found at small, towered airports that can then be used to estimate annual operations at non-towered airports nationally or by climate region. Consequently, the research team cannot recommend using a standard ratio(s) of instrument flight plans to total operations for estimating annual airport operations. However, since IFR operations are tracked by the FAA for all airports, an IFPTO could theoretically be computed for a specific airport by sampling all operations, counting all IFR flight plans filed for that same time period from FAA records, and then determining the ratio. The number and times of the samples will impact the results, so care should be taken to ensure operations sampled are truly representative of the actual operations that occur throughout the year. While sampling scenarios for IFPTO were not studied in this project, two weeks per season will most likely be needed to adequately cover variations in activity by day of week, weather, and season (see the next section for research completed on sampling sizes and timeframes). These IFPTO ratio(s) could then theoretically be used to project total operations at that specific airport from total FAA tracked IFR operations for that airport. However, the IFPTO ratios would need to be updated regularly to ensure they remained representative.

Extrapolating from a Sample Count

An analysis was performed on two methods to extrapolate a sample count of aircraft operations into an annual estimate of aircraft operations. The first method was a statistical extrapolation that follows FAA-APO-85-7, *Statistical Sampling of Aircraft Operations at Non-Towered Airports.* Based on the analysis using this method and four sampling scenarios, the preferred statistical extrapolating scenario is to sample two weeks per season. This produced the smallest range of estimated operations to actual operations at the test airports. This is consistent with the previous research results discussed in *ACRP Synthesis 4: Counting Aircraft Operations at Non-Towered Airports.*

The second method studied for extrapolating a sample of airport operations into an annual estimate was by the use of regional monthly or seasonal adjustment factors developed from small, towered airports (i.e., STAD). Based on the statistical analyses, the sampling scenario of two weeks each season is still preferred by the research team when using regional monthly or seasonal adjustment factors. While the statistical analyses did not find a significant difference between the sampling scenarios except for one month winter and one month spring, summer, or fall, there is a difference in the average percent difference and the range of percent differences that may be observed in Table 3-8 in Chapter 3. The two weeks each season sampling scenario has a combination of statistics reported that indicate preference over the other methods. To determine if a statistical significance truly exists for these scenarios, more airports would need to be studied in a future research project.

Using the regional monthly/seasonal adjustment factor method makes several assumptions, one being that variations in traffic at the STAD airports adequately represent traffic at non-towered airports. This method also requires calculating the adjustment factors, which are not needed if the statistical extrapolation process outlined in FAA-APO-85-7 is followed. The FAA-APO-85-7 method uses sample counts from two weeks each season from the specific airport where operations are being estimated, rather than depending on external factors. Additionally, use of FAA-APO-85-7 provides a percent sampling error to measure the precision of the annual operations estimate. The monthly/seasonal adjustment factor does not provide a percent sampling error. For all these reasons, the research team believes that statistical extrapolation is the favored process.

Consequently, to estimate operations at a non-towered airport, the research team recommends taking sample counts at the airport for a minimum of two weeks in each season and then using the statistical process outlined in FAA Report No. FAA-APO-85-7, *Statistical Sampling of Aircraft Operations at Non-Towered Airports*, to extrapolate the samples into an annual estimate.

Aircraft Traffic Counters

This research involved evaluating four different aircraft traffic counting technologies (that can be used to take samples that are then extrapolated into an annual operations estimate for an airport). The technology identified for evaluation included the following:

1. ACC (portable acoustic counter),
2. SMAC (portable acoustic counter),
3. S/TC (portable camera with infrared night vision), and
4. VID (stationary) with ADS-B transponder receiver (stationary).

Please refer to Research Approach in Chapter 2 for detailed information on the technology and the evaluation methods.

Automated Acoustical Counter

Acoustical counters have some inherent limitations, but they can offer a reasonable estimate of operations for a reasonable cost if positioned appropriately along the runway and the resulting data is audited correctly. Acoustically based counters record takeoffs and work on the assumption that for every takeoff there is a landing, so the total count is doubled for an estimate of operations. (Note: The original acoustically based counters used analog recordings on cassette tapes, which were then listened to and audited for aircraft and non-aircraft sounds. This form of acoustical counter is no longer manufactured. The new generation of acoustical counters are digital and do not offer a listening option for auditing the sounds recorded. While the analog recorders were extremely more labor intensive than the new digital ones, they may have been more accurate in part because of the ability to audit the cassette tape.)

The AAC is rugged, dependable, and can be left for months at a time even in below freezing temperatures when a solar panel option is used. On a typical single runway airport, the AAC offers a fairly accurate estimation of annual operations if multiple units are used and positioned properly.

The manufacturer of the AAC tested claims that recorded takeoffs will be within 10% of actual takeoffs. This claim was substantiated when at least one counter was within about

700 feet of a point perpendicular to the aircraft's point of rotation (lift-off point) and flight path.

The AAC was originally designed for use at small airports with short runways (e.g., approximately 2,000–3,000 feet). Once the runway gets much longer than this, multiple units are needed to achieve the claimed accuracy rate. (The units cost approximately $4,800 each.) However, when more than one counter is used, the raw data will likely need to be manually manipulated to remove duplicate counts because there will be times when more than one counter counts the same takeoff. The manufacturer of the unit tested did not anticipate the use of multiple counters so there was no automated feature to remove double counts from the raw data and the process was cumbersome, time consuming, and prone to human error. Additionally, the more counters that are used on a runway, the more susceptible the results are to human error because removing duplicate counts is tedious but requires great attention to detail.

The results of the study appear to indicate that the AAC can be positioned as far as 250 feet from the runway centerline and still identify an aircraft takeoff if positioned close enough perpendicularly to the point of aircraft rotation, as described above. However, use of the counters on an airport with multiple runways is very difficult because of double counting, various wind conditions, and numerous possible rotation points.

It is important to note that the AAC has some trouble identifying exceptionally quiet aircraft. The Continental O-300 SER was the engine in a Cessna 172 based at one of the test airports, and the counter missed it the majority of the time.

The longest study with the most data was performed at Indianapolis Executive Airport (5,500-foot runway) where three counters together produced results within 8% of actual takeoffs. On average across all the airports when just one counter was used in the middle of the runway, the equipment caught less than 50% of the airport's traffic.

AAC Highlights. Best used at airports with single runways with RSAs of 500 feet or less that do not experience significant traffic by exceptionally quiet aircraft.

- 90% accuracy or better can be achieved if located properly.
- Locations need to be sufficiently tested to ensure takeoffs are being recorded.
- Aircraft lift-off (rotation point) should be within approximately 700 feet of a point perpendicular of the counter to be consistently counted (Figure 4-1).
- Multiple counters are required for runways approaching 3,000 ft. or greater. This makes this option more labor intensive.
- Exceptionally quite aircraft are missed more often than counted (e.g., Cessna 172 with Continental O-300 SER engine was missed at a distance of approximately 50 feet of the unit). These are typically SEP aircraft. Jets, turbo props, and multi-engine piston aircraft are typically louder and are not missed as often.
- Helicopters are harder to count because they do not have a uniform landing path; to be counted they have to fly over the general area of the counter to be detected.
- Airports with multiple runways are difficult to count with consistent, acceptable accuracy (Figure 4-2).
- No information on aircraft type, make, or model is provided.
- The counter achieved 90% or greater accuracy when positioned as far away as 250 feet from the runway centerline. (FAA required submission of FAA Form 7460 and units had to be outside of the RSA.)

Sound-Level Meter Acoustical Counter

Also acoustically based, the SMAC is a portable unit that counts takeoffs, which are then doubled for an estimation of operations. It is rugged, works in most all weather types, and is fairly easy to use. However, its useful life between battery charges is severely limited, especially in cold weather, and the sound-level meter must be calibrated regularly. Cost is approximately $4,800 per unit.

On a typical single runway airport, the SMAC performs similar to the AAC and also offers a fairly accurate estimation of annual operations if multiple units are used and positioned properly. The manufacturer claimed accuracy rates of 5–10% of actual operations, and like the AAC, this can likely be achieved but will require multiple units when the runway approaches 3,000 feet in length or greater. Additionally, the SMAC appeared to rely more on false positives to achieve this rate than the AAC did. More specifically, the SMAC appeared

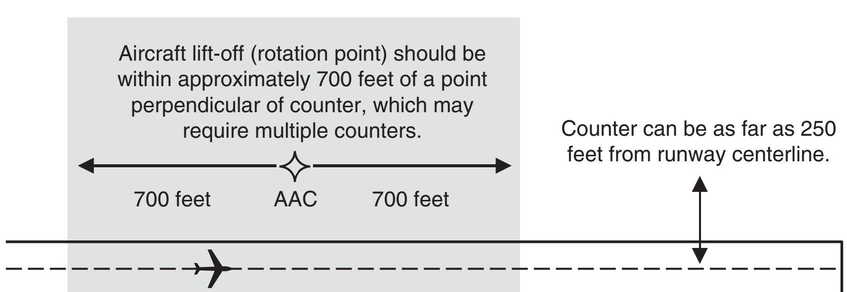


Figure 4-1. Aircraft lift-off.

Prepared by: Woolpert, Inc.

Figure 4-2. Example of configuration conducive for AAC.

to count a large number of non-events, which were included in the total and thereby significantly improved its computed accuracy level.

The SMAC is more impacted by distance from the runway centerline than the AAC (optimal seems to be 75 feet or less). The farther away from the runway centerline, the more difficulty it has detecting takeoffs. For this same reason, it is a bit more likely to miss a touch-and-go than the AAC. However, at closer distances to the runway (e.g., 50 feet), it seems better at detecting takeoffs by the relatively quieter aircraft (Cessna 172 with Continental O-300 SER) than the AAC. At 250 feet from the centerline, the research team was unable to achieve an acceptable level of performance.

Like the AAC, when more than one counter is used, the raw data has to be manually manipulated to remove duplicate counts. The use of multiple counters is not addressed in the equipment user manual so there was no automated feature for removing the duplicates and the process was cumbersome, time consuming, and prone to human error. Additionally, the software included with the counter for performing the statistical extrapolation outlined in FAA-APO-85-7 was not designed to take into account the use of multiple counters, so it could not be used without some reprogramming.

Also like the AAC, use of the counters on an airport with multiple runways is very difficult because of double counting, various wind conditions, and numerous possible rotation points.

SMAC Highlights. Best used at airports with single runways and RSAs of 150 feet or less that do not experience significant traffic by exceptionally quiet aircraft.

- 90% accuracy or better can be achieved if located properly and generally not more than 75 feet from runway centerline.
- Locations need to be sufficiently tested to ensure takeoffs are being recorded.
- Aircraft lift-off (rotation point) needs to be within approximately 700 feet of a point perpendicular of the counter to be consistently counted (Figure 4-3).
- Multiple counters are required for runways approaching 3,000 ft. or greater; this makes this option more labor intensive.
- Exceptionally quite aircraft are missed at distances greater than approximately 50 feet of the runway centerline (e.g., Cessna 172 with Continental O-300 SER engine). These are typically SEP aircraft. Jets, turbo props, and multi-engine

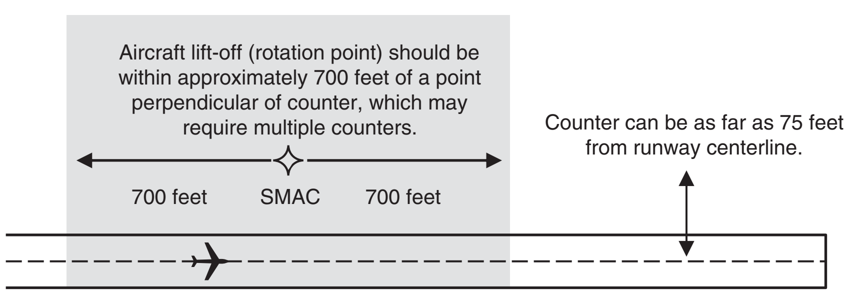


Figure 4-3. Aircraft lift-off.

piston aircraft are typically louder and are not missed as often.
- Helicopters are harder to count because they do not have a uniform landing path; to be counted they have to fly over the general area of the counter to be detected.
- No information on aircraft type, make, or model is provided.
- Airports with multiple runways are difficult to count with consistent, acceptable accuracy (Figure 4-4).
- The counter achieved 90% or greater accuracy when positioned as far away as 250 feet from the runway centerline. (FAA required submission of FAA Form 7460 and units had to be outside of the RSA.)

Security/Trail Camera

A more recent way to count aircraft operations is with the use of motion detection cameras. These can be as simple as a stand-alone S/TC or as sophisticated as a VID system, which is described next. The S/TC that are self-contained are the easiest to use and install since there are no power needs in the field. A stand-alone, solar powered camera with a range of 100 feet can be purchased for under $1,000 (which includes memory cards, batteries, solar panel, and cabling).

The S/TC tested had a passive infrared motion detector with a nighttime infrared illuminator. When located correctly on an airport conducive for its use, it can provide an exceptionally high level of accuracy in recording aircraft entering and exiting the runway environment, which can be equated to takeoffs and landings. However, it cannot count touch-and-goes. At less than $1,000 per unit, it can be a cost-effective way to estimate operations for airports with little touch-and-go activity or where the percentage of touch-and-goes is known. Use of this type of equipment gives the added benefit of knowing aircraft registration numbers, but it also requires manual review of the images to determine total operations and registration numbers. This is time consuming at a busy airport.

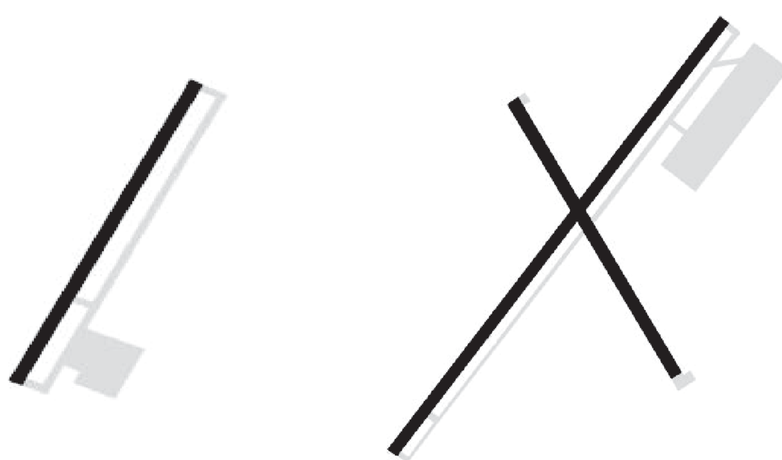
Security/Trail Camera Highlights. Best used at airports with centralized terminal and hangar area with limited access points and little touch-and-go activity (Figure 4-5).

- Accuracy levels approaching 100% can be achieved for recording aircraft entering or exiting the runway environment.
- Unable to count touch-and-goes.
- Exceptionally slow moving aircraft may be missed.
- As ambient temperature approaches temperature of target aircraft, target may be missed.
- Labor intensive because manual tally of images is required.
- Information on aircraft type, make, and model can be obtained from aircraft registration number.
- Low cost for airports with simple airfield configurations.
- Can also be used for detecting wildlife.

VID and ADS-B Transponder Receiver

Also camera based, the VID system provides a more comprehensive counting package, but also comes with a much higher price tag. The unit tested (two cameras, ADS-B transponder receiver, and web portal with service contract) cost $36,000 for the seven months it was leased. As the airfield configuration becomes more complex, more cameras are needed and the cost increases accordingly. Once installed, the annual service contract varies depending on the amount of traffic the airport experiences.

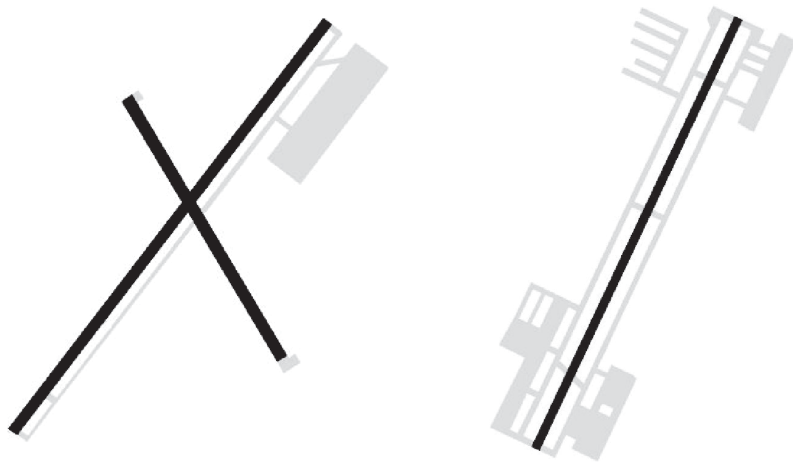
The service provider also supplements the camera equipment with the FAA's electronic tracking of aircraft known as the ASDI. If positioned correctly on an airfield with a conducive configuration, the VID can provide a reasonable level of



Prepared by: Woolpert, Inc.

Figure 4-4. Example of configuration conducive for SMAC.

Example of configuration conducive for S/TC. Example of difficult configuration for S/TC.



Prepared by: Woolpert, Inc.

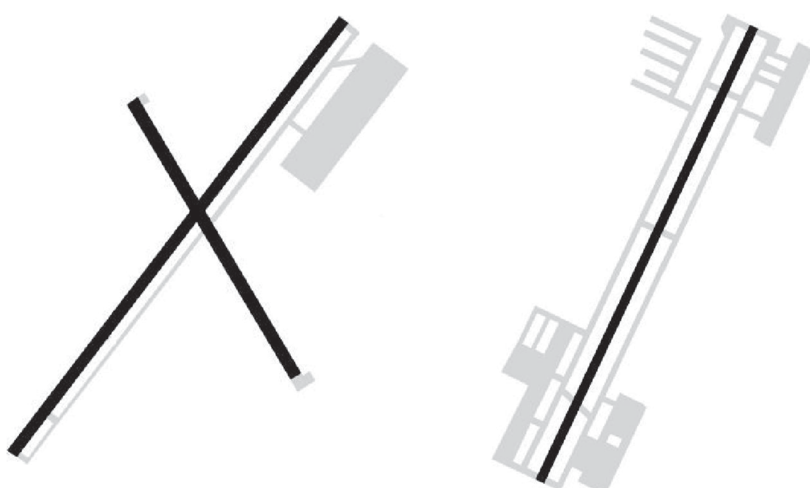
Figure 4-5. Example of configuration for S/TC.

accuracy in recording aircraft entering and exiting the runway environment, which can be equated to takeoffs and landings. It also offers detailed information on the aircraft type, make, model, owner, etc. Like the security/trail cameras, it does not appear capable of counting touch-and-goes. The VID is expensive and requires an annual service contract; however, it can offer a low labor intensive way to estimate operations for airports with little touch-and-go activity or where the percentage of touch-and-goes is known. The transponder receiver, programmed to detect ADS-B transmissions, did not perform well because of the very low number of aircraft equipped with ADS-B technology and because of technical issues with the equipment and software itself. Until the majority of the U.S. general aviation fleet becomes equipped with ADS-B, this technology will not provide a reasonably accurate way to count an airport's traffic.

VID and ADS-B Transponder Receiver Highlights. Best used at airports with centralized terminal and hangar areas with limited access points and little touch-and-go activity (Figure 4-6).

- Accuracy levels as high as 90% were achieved for recording aircraft entering or exiting the runway environment.
- Unable to count touch-and-goes.
- ADS-B transponder receiver option adds little to no value considering the low equipage rate of the U.S. general aviation fleet with ADS-B out.

Example of configuration conducive for VID. Example of difficult configuration for VID.



Prepared by: Woolpert, Inc.

Figure 4-6. Examples of VID configurations.

- Most expensive option.
- Least labor intensive option.
- Requires service contract.
- Can also be used for automated billing of landing fees.

Suggested Research

While still the best option, the current practice of sampling operations with aircraft traffic counting technology is subject to two types of errors: equipment error and sampling error. If an accurate, but relatively inexpensive, aircraft traffic counter were developed that could be used regardless of the airport configuration and traffic mix, it could be deployed at most all non-towered airports and left in place year-round—alleviating the need for sampling all together. While the existing aircraft traffic counting technology can provide reasonable estimates of operations in certain conditions, better and less expensive equipment is needed if truly accurate and comparable data is desired on a large scale basis.

If the existing acoustical counting equipment is ever improved to better detect the quieter aircraft and to automate the use of multiple counters on one runway, additional testing of this equipment would be warranted.

Toward the end of this research project, an inquiry was received from a company with a new type of technology for counting aircraft. The technology monitors the airport Unicom frequency and uses automated speech recognition to identify and record airport traffic. The company's system literature purports the ability to provide information about the aircraft, including the date and time, aircraft make and model, aircraft type, operation type (e.g., overflight, takeoff, landing), runway used, and optional registration number and picture of the aircraft. This technology should be monitored for possible future evaluation as a way to provide aircraft operations tallies at non-towered airports.

As the deadline for incorporating ADS-B out technology into all aircraft that operate in specific U.S. airspace gets closer, this technology should be readdressed. While most non-towered airports are typically not inside the airspace where ADS-B enabled avionics will be required, some may be near enough to it that the vast majority of the aircraft using them will be equipped with it. And, as general aviation aircraft owners learn the benefits of ADS-B out technology, more are likely to equip their aircraft accordingly. In short, if the overall fleet equipped with ADS-B capable avionics reaches high enough levels, transponder receivers, with the correct algorithms programmed, could be a viable option for counting aircraft operations at non-towered airports.

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APPENDIX A

Supporting Statistical Information for Chapter 3

Appendix A provides information for those readers of the report that desire more details on the work performed to support the findings in Chapter 3, *Methods for Estimating Annual Airport Operations,* on OPBA and extrapolation from a sample count.

OPBA Method to Estimate Annual Airport Operations

The objective of this research task was to determine if there was a consistent number(s) of OPBA that occur at small, towered airports and if it varied by climate or population, and if having a flight school affected this number. Since there is no valid source for operations data at non-towered airports, data on small, towered airports were used as a proxy for non-towered airports. Chapter 2 includes a description of the STAD developed for this research project. Initial analysis revealed that an extremely large range of OPBAs exist for the STAD airports overall and by region, and practical use of any averages would not produce confident results. With this in mind, the research team attempted to actually model total OPBA through regression analysis to determine if an equation could be produced that offered better results. To do this, the research team modeled total OPBA at non-towered airports from operations data at small, towered airports using information about the population, NOAA climate region, and flight schools.

The sources for the data on the STAD airports used in this analysis were the FAA TAF and the FAA OPSNET databases from 2006 to 2010 (see Chapter 2 on dataset sources). To more accurately describe the operations at a non-towered airport, total general aviation operations at small, towered airports were used in the analysis rather than total operations.

Table A-1 identifies the name of each variable, its description, and its sources used in this analysis. This table may be referred to while reading the analysis that follows. Table A-2 summarizes the results for the analysis of the OPBA for the 205 STAD airports that were used in this study. These tables are repeated in this appendix for convenience of the reader. The 95% confidence intervals for the OPBAs and the OPBA ranges shown in Table A-2 highlight the wide range of OPBA within the STAD.

Averaging the Data for Years 2006–2010

For each airport, data from each of the five years from 2006 to 2010 were collected and stored in the STAD. The research team analyzed the data to see if an average of the five years of data for each airport could be used instead of the data from each year. An average of the five years of airport data allows for statistically accurate analysis of the 205 airports in the dataset, and simplifies the statistical analyses and outputs.

To test the use of averages, the research team analyzed the operations data to see if there was a statistically significant difference between the GA OPBA aircraft data for each of the five years. A one-way analysis of variance (ANOVA) test was performed to determine if the Total GA OPBA (Total GA OPBA) have a statistically significant difference by year. The ANOVA test is used when three or more groups are studied. The ANOVA analyzes the variances and determines if there is a significant difference between the true means of the groups. In this test, a p-value (or probability number) is determined, which is a numerical way of describing the significance of results. Using the data and a 95% confidence level (or an alpha of 0.05), the research team could not show a statistically significant difference between the true means for Total GA OPBA for the years 2006–2010. While there is no statistically significant difference, there is an observable difference in the averages of the data. The ANOVA determines if there is a statistically significant difference in the true means for each group. The presence of a p-value greater than or equal to 0.05 indicates that the true means of each of the five years are believed to be the same, as there is not

Table A-1. Variables and descriptions of sources.

Variable	Description	Source
AvgOPBA	Average general aviation operations per based aircraft for each airport 2006-2010.	OPBA calculated from OPSNET and TAF data
Enp	Enplanements or revenue passenger boardings	TAF
OPS	Average general aviation operations for each airport 2006-2010	OPSNET Data
AvgPop	The average population for the years 2006-2010 for the city or town surrounding the airport	U.S. Census. United States Census Bureau. Population Estimates 2000-2009 http://www.census.gov/popest/data/cities/totals/2009/SUB-EST2009-4.html United States Census Bureau. 2010 Population Finder http://www.census.gov/popfinder/index.php
Pop Scaled	The average population scaled by 10,000 for the city or town surrounding the airport for the years 2006-2010	AvgPop/10,000
NFS	The number of flight schools at the airport	AOPA (Training and Safety) http://www.aopa.org/learntofly/school/index.cfm
FS Y/N	The presence of a flight school. (1=Yes and 0=No)	AOPA (Training and Safety) http://www.aopa.org/learntofly/school/index.cfm
CTHrs	Yearly hours of control tower operations	FAA Airport Facility Directory. (March 2013 data as no historical data was available)
C	1 for Central; 0 for other regions	Definition from NOAA and data from OPSNET
EN	1 for East North Central; 0 for other regions	Definition from NOAA and data from OPSNET
NE	1 for Northeast; 0 for other regions	Definition from NOAA and data from OPSNET
NW	1 for Northwest; 0 for other regions	Definition from NOAA and data from OPSNET
S	1 for South; 0 for other regions	Definition from NOAA and data from OPSNET
SE	1 for Southeast; 0 for other regions	Definition from NOAA and data from OPSNET
SW	1 for Southwest; 0 for other regions	Definition from NOAA and data from OPSNET
CM	1 for Commercial airport; 0 for GA or RL	National Plan of Integrated Airport Systems
RL	1 for Reliever airport; 0 for CM or GA	National Plan of Integrated Airport Systems

Notes: West is not defined here, but it occurs when all other regions are set to 0.
GA is not defined here, but it occurs when CM and RL are set to 0.
North West Central is not included because there are no airports from this region that meet the selection criteria for airports to be included in the dataset.
Prepared by: Purdue University

enough evidence to show that the true means are different. In this case, the p-value was 0.624; therefore, the research team concludes that the Total GA OPBA is not different for each year and the use of the 5-year average was statistically acceptable.

As a result, the Total GA OPBA ratios for the five years for each airport were averaged to obtain the Average GA OPBA (AvgOPBA) for each of the Small Non-Towered Airports. AvgOPBA was then used in the following regression analysis.

Analysis

Analysis of regression models was performed to determine if there is a consistent number(s) of OPBA that occur at small, towered airports (that could then be applied to non-towered airports). The regression analysis also considered if the OPBA varied by climate or population and if having a flight school affected this number. Regression analysis of the data was used to determine the effect that each of the variables in Table A-1 has on AvgOPBA in the STAD. The analysis includes:

A. Full model and reduced model using AvgOPBA.
B. Transformation of AvgOPBA and average based aircraft (AvgBA).
C. Full model and reduced model using transformed data.
D. Full model and reduced model using operations (OPS).
E. Overview of models and conclusions.

A full model regression uses every variable, with no variables removed from the model. A reduced model regression removes variables from the full model one at a time until the remaining variables are all statistically significant at the 0.05 level. The reduced model is used to filter out uninformative variables and, thereby, simplify the model. The reduced model may explain nearly as much as the complete model, but with fewer pieces of information.

Table A-2. Summary of small towered airport data by region used in this study.

NOAA Climate region	Number of airports	AvgBA per region	Avg Ops per region	AvgPop	OPBA mean	OPBA median	OPBA 95% Confidence Interval for the median	OPBA range Low	OPBA range High
Alaska	1	965.8	152,018	283,382	157.40	157.40	NA	NA	NA
Central	33	141.01	49,187	162,441	429.54	360.13	(298.02, 426.85)	201.75	1,015.54
E. N. Central	13	188.52	67,823	260,933	473.92	462.29	(266.65, 550.52)	177.42	798.85
Hawaii	1	22.80	104,224	13,689	4,771.68	4771.6	NA	NA	NA
Northeast	28	187.06	72,081	353,687	432.95	408.37	(351.95, 504.20)	225.91	828.52
Northwest	8	202.90	80,577	224,704	382.95	779.38	(264.80, 453.03)	219.87	779.38
South	41	154.19	65,312	352,947	597.89	338.00	(302.52, 522.53)	132.17	2,481.89
Southeast	38	212.66	95,457	171,804	561.74	439.42	(338.62, 572.66)	190.89	2,491.54
Southwest	15	394.01	16,802	391,318	487.23	396.66	(336.31, 646.39)	192.52	819.86
West	27	381.98	124,391	388,546	370.13	326.30	(282.28, 362.85)	139.69	875.89
W.N. Central	0	NA	NA	NA	NA	NA	NA	NA	NA
Overall	205	222.35	85,890	394,118	501.68	377.78	(350.30, 412.86)	132.17	4,471.68

Legend:
Avg = Average
BA = Based Aircraft
Ops = Operations
OPBA = Operations per Based Aircraft
NA = Not Applicable
Prepared by: Purdue University

Each regression was also checked to determine if it met the necessary assumptions for statistical validity. For regression and ANOVA to be valid, the following statistical standards, or assumptions, must be met:

1. The sample is representative of the population.
2. The independent variables are linearly independent (are not good predictors of each other), and are measured with no error.
3. There is a constant variance (the variance of y is the same for all values of x; and there is no pattern in the variance).
4. Linearity exists (mean response y has a straight line relationship with x).
5. Normality exists (for any fixed value of x the response y varies according to a normal distribution).
6. Independence exists (y variable responses are independent of each other).

A. Full model and reduced model using AvgOPBA. First, the full model regression was created using AvgOPBA as the variable to be estimated by the regression equation. The variables used in the full model regression analysis are: Avg OPBA, AvgBA, Number of Flight Schools at the airport (NFS), Flight School Yes/No (FS Y/N), Based Aircraft (BA), Population (Pop Scaled), Yearly Hours of Control Tower Operations (CTHrs), Central (C), East North Central (EN), Northeast (NE), South (S), Southeast (SE), Southwest (SW), Commercial airport (CM), Reliever airport (RL) (see Table A-1 for descriptions of these variables). Table A-3 provides supplemental statistics for the analysis.

The regression equation for the full model using AvgOPBA is as follows:

$$\begin{aligned} \text{AvgOPBA} = {} & 347 - 1.21\ \text{AvgBA} + 24\ \text{NFS} + 77\ \text{FS Y/N} \\ & + 0.603\ \text{Pop Scaled} + 0.0534\ \text{CTHrs} - 180\ \text{C} \\ & - 185\ \text{EN} - 188\ \text{NE} - 168\ \text{NW} + 44\ \text{S} - 27\ \text{SE} \\ & + 129\ \text{SW} + 85\ \text{CM} + 201\ \text{RL} \end{aligned}$$

The regression model is statistically significant at the 95% level (alpha = 0.05). The R-Squared (adjusted) equals 27.6%. Adjusted R-Squared [R-Sq(adj)] is the proportion of the total variation of outcomes explained by the model, taking into consideration the number of variables in the model. R-Sq(adj) measures how well the independent variables [in this case based aircraft, flight schools, population, climate, and airport category (commercial, reliever, or GA)] explain the variation of the dependent variable (in this case the AvgOPBA). Residual

Table A-3. Supplemental statistics showing significance of each variable in the full model using AvgOPBA.

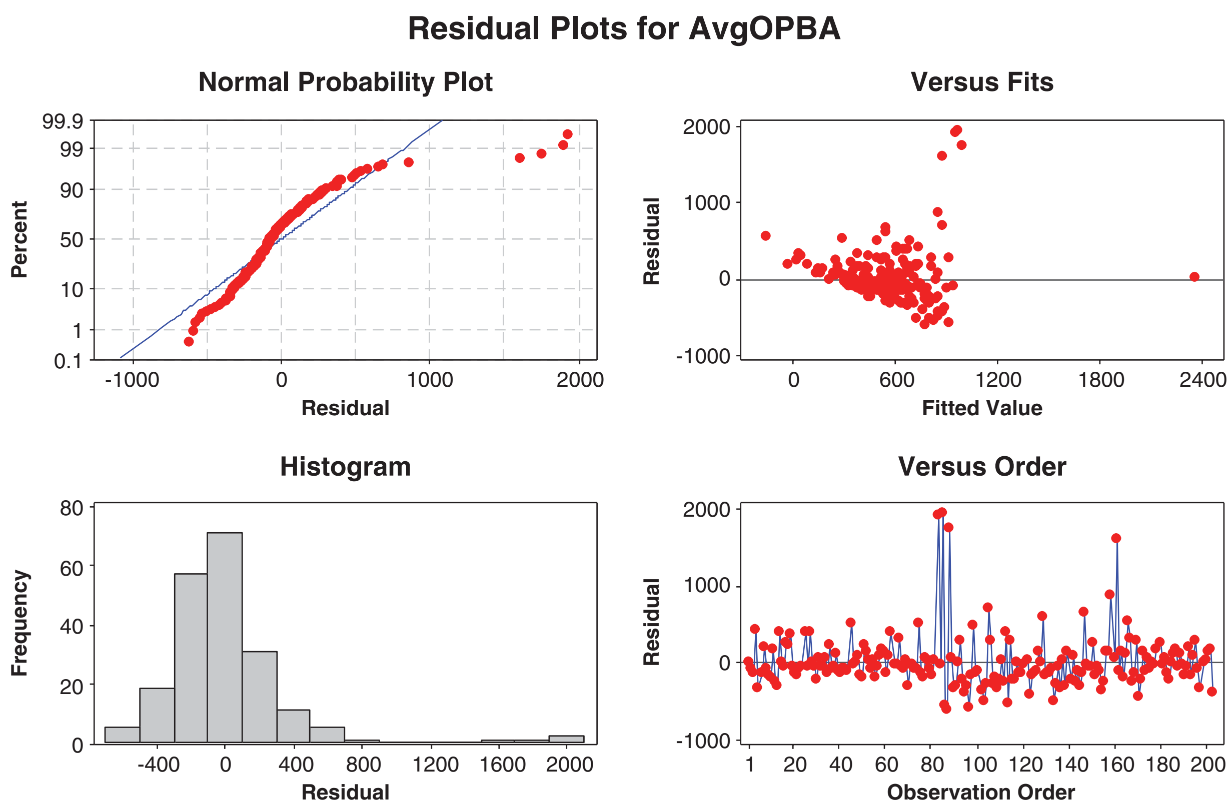
p value=0.000

Predictor	Coef	SECoef	t	p
Constant	346.5	200.7	1.73	0.086
AvBA	-1.2134	0.2559	-4.74	0.000
NFS	23.99	14.02	1.71	0.089
FSY/N	77.5	105.1	0.74	0.462
Pop Scaled	0.6027	0.1335	4.51	0.000
CTHrs	0.05338	0.03076	1.74	0.084
C	-179.5	112.5	-1.59	0.112
EN	-184.8	132.5	-1.39	0.165
NE	-188.3	112.3	-1.68	0.095
NW	-168.1	153.5	-1.09	0.275
S	43.7	103.4	0.42	0.673
SE	-27.3	103.2	-0.26	0.791
SW	129.4	120.9	1.07	0.286
CM	85.5	100.5	0.85	0.396
RL	201.09	68.79	2.92	0.004

Prepared by: Purdue University

plots are used by statisticians to assess if a regression model is a good fit to the data, and to examine the underlying statistical assumptions required for regression.

The analysis of the residual plots (see Figure A-1) indicated that regression is invalid due to the violation of two required statistical assumptions described above that must be met in order to use regression. The two assumptions are constant variance (right half of the residual plots in Figure A-1) and non-normal residuals (left half of the residual plots in Figure A-1). Ideally, the normal probability plot will have red dots tracing over the blue line; and the top right graph (Fitted Value vs. Residual) will appear to be scattered in a random pat-



Prepared by: Purdue University

Figure A-1. Residual plots for **AvgOPBA** *for full model.*

tern, or sometimes thought of as birdshot. In this case, the red dots do not follow the line closely enough to be considered normally distributed (and the histogram below it reinforces this view). The variance is not believed to be constant as the red dots in the top right graph are scattered in a cone pattern, so that the variance moves from small to larger as the fitted value for AvgOPBA increases.

Next, the reduced model regression was analyzed using AvgOPBA. The variables used in the reduced model regression analysis are: AvgOPBA, AvgBA, NFS, Pop scaled, S, SW, RL. (See Table A-1 for descriptions of these variables.) (Note: A reduced model regression removes variables from the full model one at a time until the remaining variables were all statistically significant at 0.05.) Table A-4 provides supplemental statistics for the analysis.

The regression equation for the Reduced Model using AvgOPBA is as follows:

$$\text{AvgOPBA} = 572 - .1.11\ \text{AvgBA} + 30.9\ \text{NFS} + 0.613\ \text{Pop scaled} + 146\ \text{S} + 214\ \text{SW} + 177\ \text{RL}$$

The regression is statistically significant at the 95% level (alpha = 0.05). The R-Sq(adj) equals 27.5%. R-Sq(adj) is the proportion of the total variation of outcomes explained by the model, taking into consideration the number of variables in the model. R-Sq(adj) measures how well the independent variables (in this case based aircraft, flight schools, population, climate, and airport category) explain the variation of the dependent variable (in this case, AvgOPBA). Residual Plots are used by statisticians to assess if a regression model is a good fit to the data, and to examine the underlying statistical assumptions required for regression.

The analysis of the residual plots (see Figure A-2) indicated that regression is invalid due to the violation of two required statistical assumptions described earlier that must be met in order to use regression. The two assumptions are constant variance (right half of the residual plots in Figure A-2) and non-normal residuals (left half of the residual plots in Figure A-2). Ideally, the normal probability plot will have red dots tracing over the blue line; and the top right graph (Fitted Value vs. Residual) will appear to be scattered in random pattern, or sometimes thought of as birdshot. In this case, the red dots do not follow the line closely enough to be considered normally distributed (and the histogram below it reinforces this view). The variance is not believed to be constant as the red dots in the top right graph are scattered in a cone pattern, so that the variance moves from small to larger as the fitted value increases.

B. Transformation of AvgOPBA and AvgBA. As described in Section A, the violation of two statistical assumptions for regression to be used (the existence of non-constant variance and non-normally distributed residuals) resulted in invalid regression results using AvgOPBA for either the full or reduced model regression. To try to understand the non-constant variance, the variable with the most influence in the models was studied further. AvgBA is by far the largest contributor to the AvgOPBA model presented in Part A. The fitted line plot in Figure A-3 shows that there is a non-linear relationship between AvgOPBA and AvgBA. The data (red dots) appear to form a curve; therefore, the reasonable conclusion is that there is a non-linear relationship. This non-linear relationship between AvgBA and AvgOPBA appears to explain the non-constant variance and the non-normal residuals seen in the full and reduced model regression described under Part A (Figure A-1 and A-2).

In Figure A-3, the R-Sq(adj) of 14.3% means that 14.3% of the variation in AvgOPBA is explained by the variation of AvgBA. This R-Sq(adj) is typically considered to be too low for practical use in this type of application, in addition to being invalid due to not meeting the required assumptions. Comparison of this R-Sq(adj) of 14.3% to the R-Sq(adj) of approximately 27% for the models in Part A indicate that AvgBA is contributing about half of the explanation of variation.

Based on algebraic principles, it is possible to transform data to create a linear relationship. The linear relationship is necessary in order to meet the assumptions for statistical validity of the model, as described under the full and

Table A-4. Supplemental statistics showing significance of each variable in the reduced model using AvgOPBA.

p value=0.000

Predictor	Coef	SECoef	t	p
Constant	571.83	64.91	8.81	0.000
AvgBA	-1.1128	0.2308	-4.82	0.000
NFS	30.92	13.10	2.36	0.019
Pop Scaled	0.6131	0.1327	4.62	0.000
S	146.33	66.39	2.20	0.029
SW	214.5	105.0	2.04	0.042
RL	176.56	62.44	2.83	0.005

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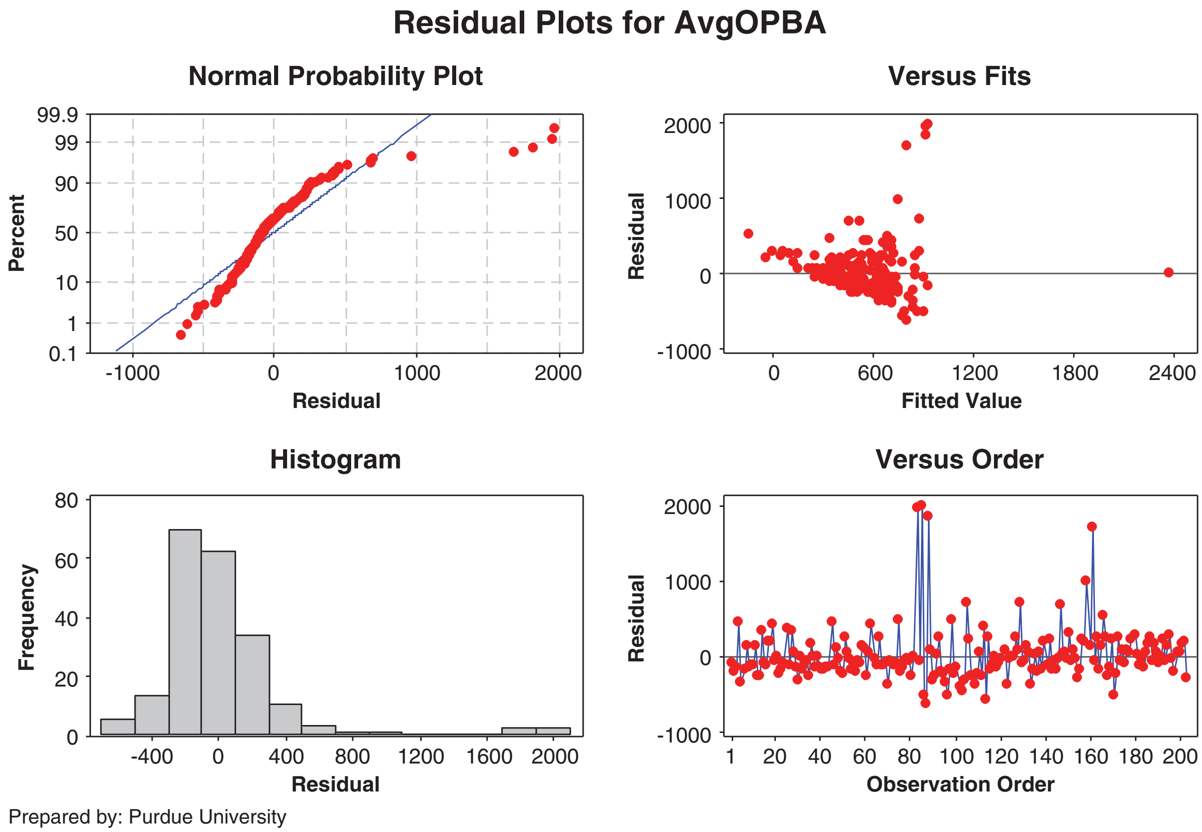

Figure A-2. Residual plots for AvgOPBA for reduced model.

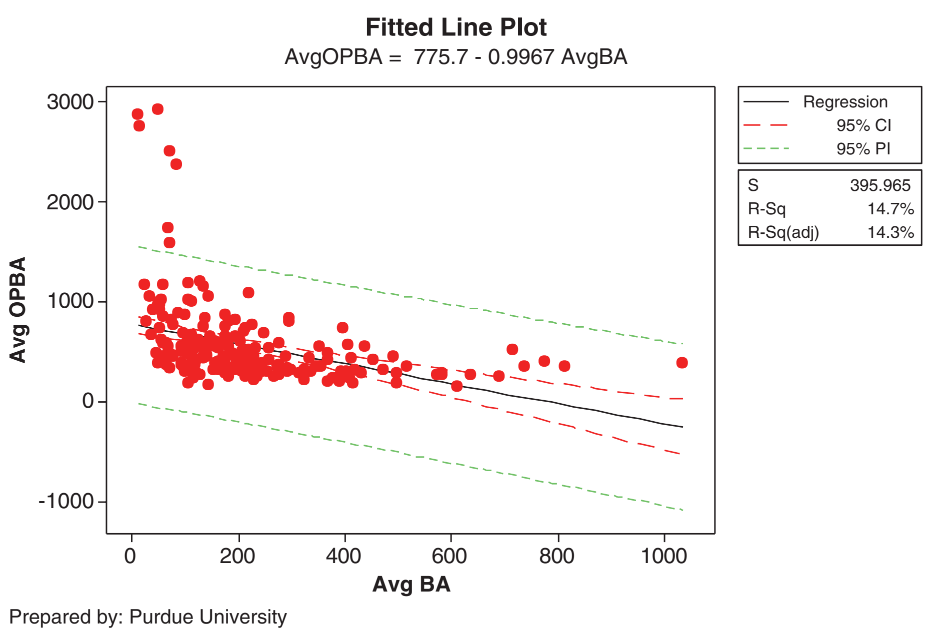

Figure A-3. Fitted line plot for AvgOPBA vs. AvgBA.

reduced model regression discussion. To transform data, a mathematical operation is performed on each data point. The regression analyses are performed using the transformed data. Several possible transformations were analyzed for this research, and the transformation that best met the required statistical assumptions was selected for further study. The AvgBA was transformed to log10AvgBA (for the log base 10 of AvgBA). The AvgOPBA was transformed to log10AvgOPBA (for the log base 10 of AvgOPBA). The fitted line plot in Figure A-4 shows a regression of the transformed data.

The fitted line plot in Figure A-4 for log10AvgBA and log10AvgOPBA reveals a linear relationship with an R-sq(adj) of 35.8% and statistical significance at alpha equals 0.05. This is an improvement over the non-transformed model with a R-Sq(adj) of 14.3%. Analysis of the transformed data using regression and the ANOVA table indicates that it is valid (as may be interpreted from the residual plots in Figure A-5) for use in regression. Therefore, the next step is to use the transformed data to build models using the other variables. Figure A-5 is much closer to the ideal residual plot than any in Part A.

C. Full model and reduced model using transformed data. Based on the findings in Part B, the full model regression using log10AvgOPBA and log10BA was performed. The variables used in the full model regression analysis are as follows: log10AvgOPBA, log10AvgBA, Pop Scaled, NFS, FS Y/N, CTHrs, C, EN, NE, NW, S, SE, SW, CM, RL. (See Table A-1 for descriptions of these variables. Note: A full model regression uses every variable, with no variables removed from the model.) Table A-5 provides supplemental statistics for the analysis.

The full model regression equation using log10AvgOPBA and log10AvgBA is as follows:

$$\begin{aligned}\text{log10AvgOPBA} = {} & 3.95 - 0.681\ \text{log10AvgBA} \\ & + 0.000215\ \text{Pop Scaled} + 0.0246\ \text{NFS} \\ & + 0.0206\ \text{FS Y/N} + 0.000036\ \text{CTHrs} \\ & - 0.153\ \text{C} - 0.0921\ \text{EN} - 0.0716\ \text{NE} \\ & - 0.0421\ \text{NW} - 0.0704\ \text{S} + 0.0079\ \text{SE} \\ & + 0.118\ \text{SW} - 0.0652\ \text{CM} - 0.0176\ \text{RL}\end{aligned}$$

The regression is statistically significant at the 95% level (alpha equals 0.05). The R-Sq(adj) equals 51%. (Note: The adjusted R-Squared is the proportion of the total variation of outcomes explained by the model taking into consideration the number of variables in the model.)

The analysis of the transformed data in this full model regression analysis is valid based on the residual plots in Figure A-6 along with its ability to meet the other regression assumptions. Figure A-6 is much closer to the ideal residual plot than any of those in Section A.

Next, the reduced model using log10AvgOPBA and log10AvgBA was analyzed. The variables used in the reduced model regression analysis are log10AvgOPBA, log10AvgBA, Pop Scaled, NFS, C, SE and SW. (See Table A-1 for descriptions of these variables. Note: A reduced model regression removes variables from the full model one at a time until the remaining variables all were statistically significant at alpha equals 0.05.) Table A-6 provides supplemental statistics for the analysis.

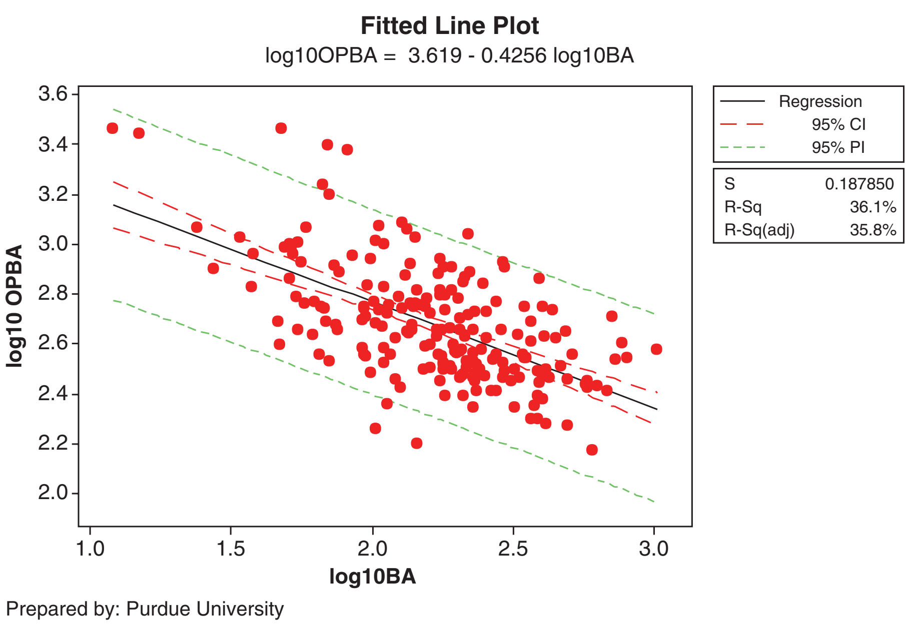

Figure A-4. Fitted line plot for Log10AvgOPBA vs. Log10AvgBA.

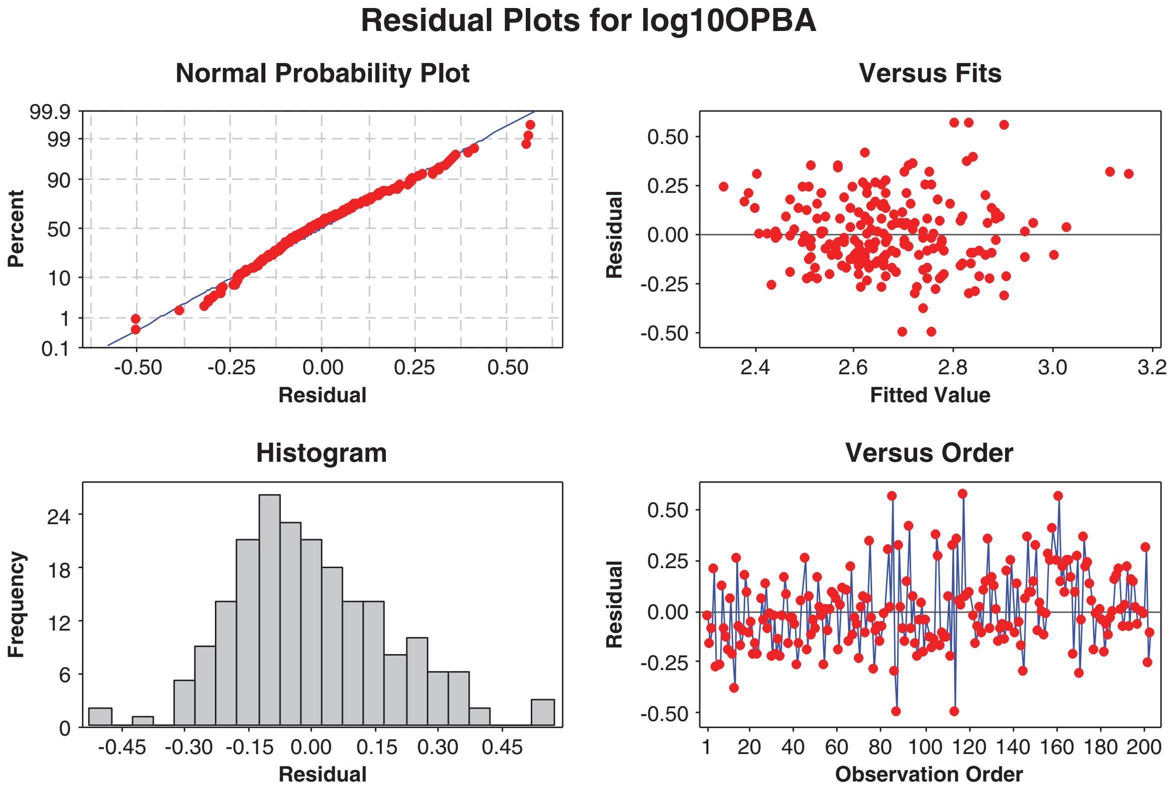

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Figure A-5. Residual plots of the transformed data.

The regression equation for the Reduced Model using log10AvgOPBA and log10AvgBA is as follows:

$$\text{log10AvgOPBA} = 3.94 - 0.621\ \text{log10AvgBA} + 0.000232\ \text{Pop scaled} + 0.0279\ \text{NFS} - 0.0797\ \text{C} + 0.0631\ \text{SE} + 0.169\ \text{SW}$$

The regression is statistically significant at the 95% level (alpha equals 0.05). The R-Sq(adj) equals 50.4%. (Note: The adjusted R-Squared is the proportion of the total variation of outcomes explained by the model taking into consideration the number of variables in the model.)

The analysis of the transformed data using a reduced model regression are valid based on the residual plots in

Table A-5. Supplemental statistics showing significance of each variable in the full model using log10AvgOPBA and log10BA.

p value=0.000

Predictor	Coef	SE Coef	t	p
Constant	3.9460	0.1579	24.99	0.000
log10 BA	-0.68147	0.05966	-11.42	0.000
Pop Scaled	0.00021468	0.00006039	3.55	0.000
NFS	0.024623	0.006093	4.04	0.000
FS Y/N	0.02058	0.04745	0.43	0.665
CTHrs	0.00003573	0.00001369	2.61	0.010
C	-0.15321	0.05006	-3.06	0.003
EN	-0.09209	0.05860	-1.57	0.118
NE	-0.07158	0.0490	-1.46	0.146
NW	-0.04212	0.0685	-0.61	0.540
S	-0.07036	0.04611	-1.53	0.129
SE	0.00788	0.04492	0.18	0.861
SW	0.11793	0.05444	2.17	0.032
CM	-0.06518	0.04750	1.37	0.172
RL	-0.01763	0.03369	-0.52	0.601

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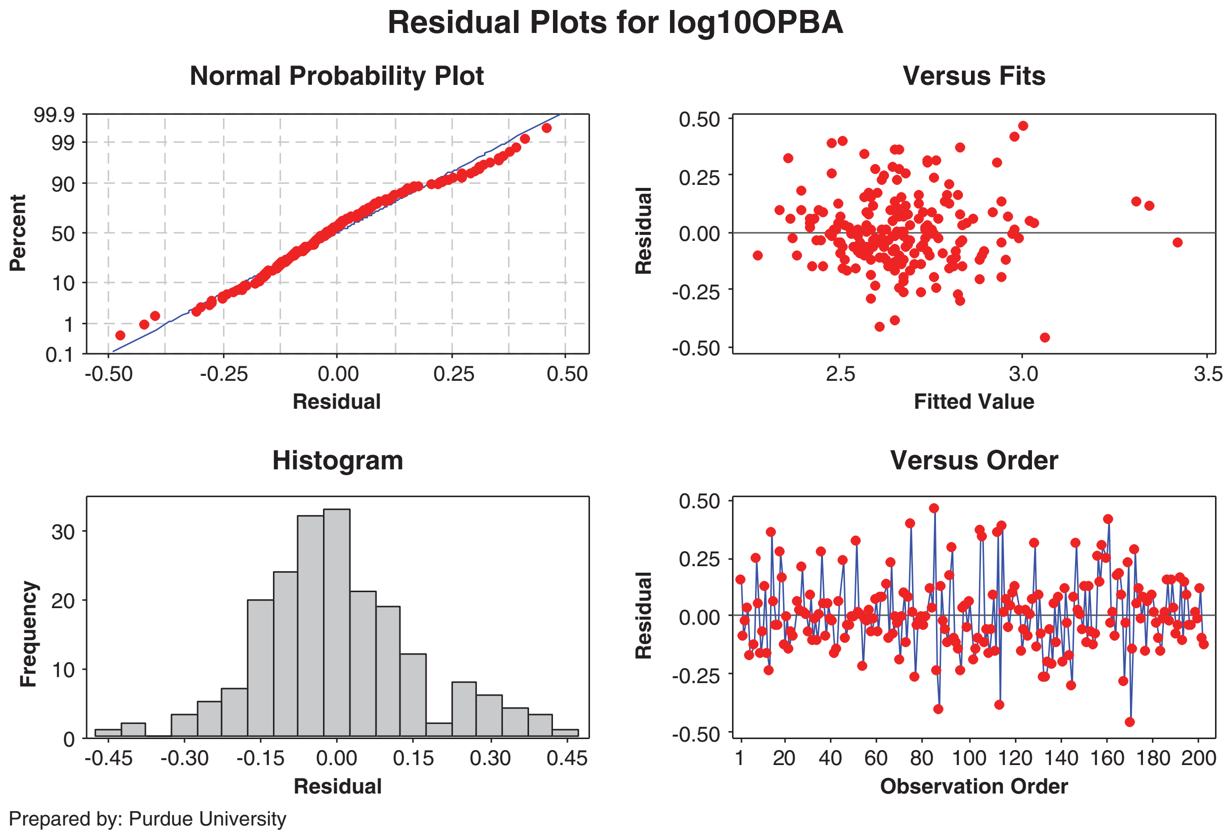

Figure A-6. Residual plots for Log10AvgOPBA for full model.

Figure A-7, along with its ability to meet the other regression assumptions.

The reduced model has a very slight reduction in R-Sq(adj) than the full model (50.4% compared to 51%). However, the reduced model is preferable to the full model because it uses only six variables, while the full model uses 14 variables. Practically speaking, to use this reduced model equation to estimate the OPBA, the only data a person needs are the number of based aircraft, the population (divided by 10,000) for the city or town surrounding the airport, the number of flight schools at the airport, and the NOAA region for the airport. However, this equation only accounts for approximately 50% of the behavior of annual operations, and therefore, it may not provide useful estimates in a practical application. If only approximately 50% of the variation of the AvgOPBA is explained by the variables in the equation (i.e., flight schools, population, climate, and airport category), then large variations from actual to estimated operations are likely to occur. Therefore, use of this model is not recommended. Nevertheless, examples using the reduced equation are explored below.

REDUCED MODEL EXAMPLES

Use of the reduced equation is explored in the following five examples. Please notice that the OPBAs estimated using the

Table A-6. Supplemental statistics showing significance of each variable in the reduced model using log10AvgOPBA and log10BA.

p value=0.000

Predictor	Coef	SECoef	t	p
Constant	3.94252	0.09797	40.24	0.000
log10BA	-0.62070	0.04791	-12.96	0.000
Pop Scaled	0.00023176	0.00005914	3.92	0.000
NFS	0.027871	0.005834	4.78	0.000
C	-0.07966	0.03351	-2.38	0.018
SE	0.06305	0.03126	2.02	0.045
SW	0.16905	0.04649	3.64	0.000

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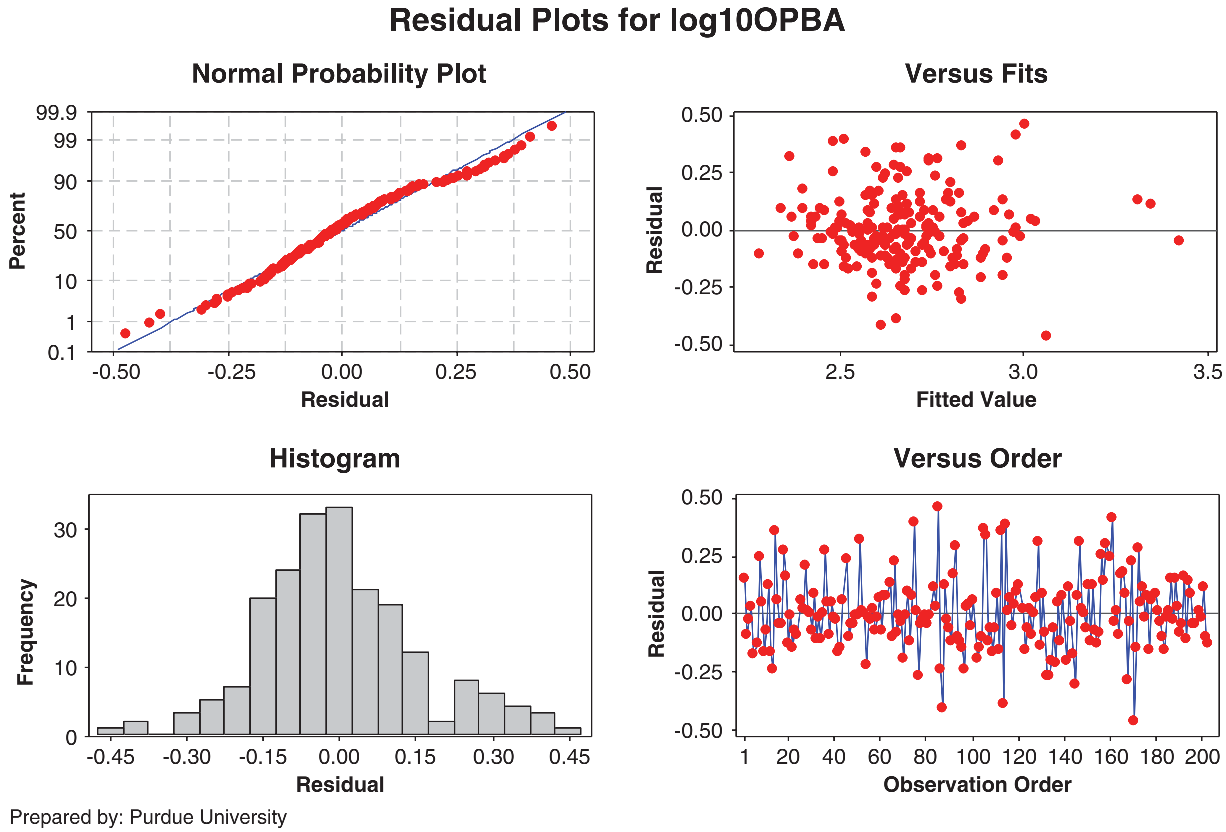

Figure A-7. Residual plots for Log10AvgOPBA for reduced model.

equations are not consistent with each other. In addition, the equation explains only 50% of the variation seen in the data, and it was developed using small towered airport operations data that may or may not represent non-towered airport operations counts.

Example 1. Consider a fictional airport in the southwest NOAA region with 100 based aircraft in a city of 100,000 people that has two flight schools. In this case BA = 100, Pop Scaled = 10, NFS = 2, C = 0, SE = 0, and SW = 1.

$$\text{log10AvgOPBA} = 3.94 - 0.621\ \log 10(100) + 0.000232\ (10) + 0.0279\ (2) - 0.0797\ (0) + 0.0631\ (0) + 0.169\ (1).$$

Solving this equation, the AvgOPBA for this airport would be 841. Since the airport has 100 based aircraft, the estimated annual operations using this equation would be 84,100.

Example 2. Consider a fictional airport in the Central NOAA region with 10 based aircraft in a city of 20,000 people that has one flight school. In this case BA = 10, Pop Scaled = 2, NFS = 1, C = 1, SE = 0, and SW = 0.

$$\text{log10AvgOPBA} = 3.94 - 0.621\ \log 10(10) + 0.000232\ (2) + 0.0279\ (1) - 0.0797\ (1) + 0.0631\ (0) + 0.169\ (0).$$

Solving this equation, the AvgOPBA for this airport would be 1852. Since the airport has 10 based aircraft, the estimated annual operations using this equation would be 18,520.

Example 3. Consider a fictional airport in the Northeast NOAA region with 10 based aircraft in a city of 200,000 people that has one flight school. In this case BA = 10, Pop Scaled = 20, NFS = 1, C = 0, SE = 0, and SW = 0.

$$\text{log10AvgOPBA} = 3.94 - 0.621\ \log 10(10) + 0.000232\ (20) + 0.0279\ (1) - 0.0797\ (0) + 0.0631\ (0) + 0.169\ (0).$$

Solving this equation, the AvgOPBA for this airport would be 2247. Since the airport has 10 based aircraft, the estimated annual operations using this equation would be 22,470.

Example 4. Consider a fictional airport in the South NOAA region with 10 based aircraft in a city of 50,000 people that has no flight schools. In this case BA = 10, Pop Scaled = 5, NFS = 0, C = 0, SE = 0, and SW = 0.

$$\text{log10AvgOPBA} = 3.94 - 0.621\ \log 10(10) + 0.000232\ (5) + 0.0279\ (0) - 0.0797\ (0) + 0.0631\ (0) + 0.169\ (0).$$

Solving this equation, the AvgOPBA for this airport would be 2090. Since the airport has 10 based aircraft, the estimated annual operations using this equation would be 20,900.

Example 5. Consider a fictional airport in the Northeast NOAA region with 300 based aircraft in a city of 200,000 people that has one flight school. In this case BA = 300, Pop Scaled = 20, NFS = 1, C = 0, SE = 0, and SW = 0.

$$\text{log10AvgOPBA} = 3.94 - 0.621\ \log 10(300) + 0.000232\ (20) + 0.0279\ (1) - 0.0797\ (0) + 0.0631\ (0) + 0.169\ (0).$$

Solving this equation, the AvgOPBA for this airport would be 272. Since the airport has 300 based aircraft, the estimated annual operations using this equation would be 81,600.

D. Full model and reduced model using OPS. Because using AvgOPBA did not prove to be a relatively accurate way to estimate operations, the research team chose to explore a different approach. While the research problem was to determine if there was a consistent number of OPBA that could be used to estimate an airport's annual OPS, the ultimate goal is to estimate the annual OPS, not the OPBA. Therefore, analysis of a regression model for estimating OPS rather than OPBA was performed.

Previous research (GRA, Inc. 2001) has shown that statistical models of operations may be more descriptive than models of operations per based aircraft. In this analysis, full and reduced regression models using OPS were analyzed using the same variables as described in Table A-1.

The variables used in the full model regression analysis are OPS, AvgBA, NFS, FS Y/N, Pop scaled, CTHrs, C, EN, NE, NW, S, SE, SW, CM, and RL. (See Table A-1 for descriptions of these variables.) Table A-7 provides supplemental statistics for the analysis.

The full model regression equation using OPS is as follows:

$$\begin{aligned}OPS = 8321 + 185\ AvgBA + 5185\ NFS + 1315\ FS\ Y/N \\ + 43.3\ Pop\ Scaled + 3.39\ CTHrs - 19462\ C - 11778\ EN \\ - 9125\ NE + 3418\ NW - 9397\ S + 5062\ SE + 45472\ SW \\ - 2670\ CM + 3353\ RL\end{aligned}$$

The regression is statistically significant at the 95% level (alpha equals 0.05). The R-Sq(adj) equals 64.6%. While this is the best adjusted R-Sq yet, the equation still only explains approximately 64% of the variation in operations. R-Sq(adj) is the proportion of the total variation of outcomes explained by the model taking into consideration the number of variables in the model. R-Sq(adj) measures how well the independent variables (in this case flight schools, based aircraft, control tower hours of operation, population, climate, and airport category) explain the variation of the dependent variable (in this case the OPS). As stated before, residual plots are used by statisticians to assess if a regression model is a good fit to its data, and to examine the underlying statistical assumptions required for regression.

The analysis of the residual plots (see Figure A-8) indicated that regression is invalid due to the violation of two required statistical assumptions described above that must be met in order to use regression. The two assumptions are constant variance (right half of the residual plots in Figure A-8) and non-normal residuals (left half of the residual plots in Figure A-8). Ideally, the normal probability plot will have red dots tracing over the blue line; and the top right graph (Fitted Value vs. Residual) will appear to be scattered in random pattern, or sometimes thought of as birdshot. In this case, the red dots do not follow the line closely enough to be considered normally distributed (and the histogram below it reinforces this view). Even if there is disagreement with how close is close enough for normality of residuals, the variance of the residuals does not appear to be constant. The variance of the residuals is not believed to be constant as the red dots in the top right graph are scattered in a wide cone pattern, so that the variance moves from small to larger as the fitted value increases.

Next, the reduced model using OPS was performed. The variables used in the reduced model regression analysis are OPS, AvgBA, NFS, SW, Pop Scaled and SE. (See Table A-1 for descriptions of these variables. Note: A reduced model regression removes variables from the full model one at a time until the remaining variables all were statistically significant at alpha equals 0.05.) Table A-8 provides supplemental statistics for the analysis.

The regression equation for the Reduced Model using OPS is as follows:

$$\begin{aligned}OPS = 16535 + 199\ AvgBA + 5174\ NFS + 44.1\ OPS\ Scaled \\ + 14880\ SE + 52389\ SW\end{aligned}$$

Table A-7. Supplemental statistics showing significance of each variable in the full model using OPS (operations).

p value=0.000

Predictor	Coef	SECoef	t	p
Constant	8321	19858	0.42	0.676
AvgBA	185.46	25.32	7.32	0.000
NFS	5185	1387	3.74	0.000
FSY/N	1315	10395	0.13	0.899
Pop Scaled	43.29	13.21	3.28	0.001
CTHrs	3.391	3.043	1.11	0.267
C	-19462	11135	-1.75	0.082
EN	-11778	13108	-0.90	0.370
NE	-9125	11106	-0.82	0.412
NW	3418	15189	0.23	0.822
S	-9397	10235	-0.92	0.360
SE	5062	10207	0.50	0.621
SW	45472	11966	3.80	0.000
CM	-2670	9939	-0.27	0.788
RL	3353	6805	0.49	0.623

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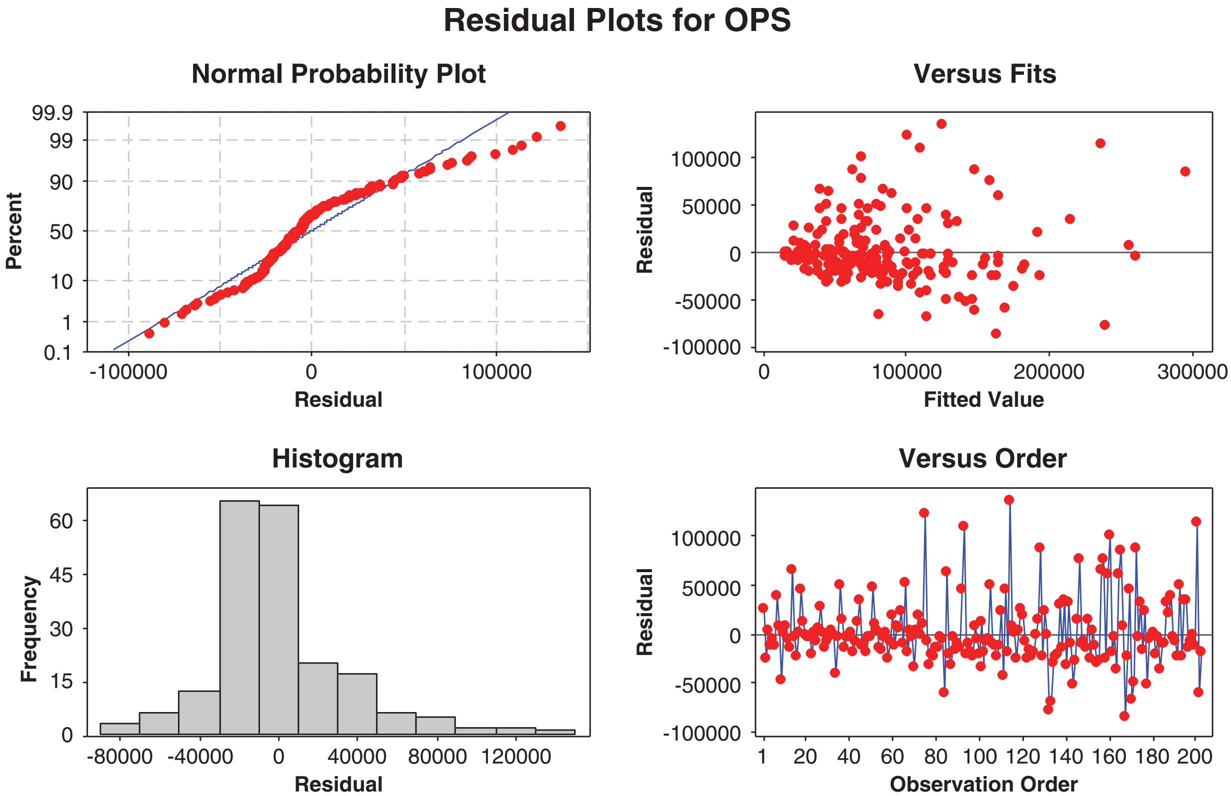

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Figure A-8. Residual plots for operations (OPS) full model.

The regression is statistically significant at the 95% level (alpha equals 0.05). The R-Sq(adj) equals 65.3%. Since R-Sq(adj) is the proportion of the total variation of outcomes explained by the model, taking into consideration the number of variables in the model, it measures how well the independent variables (in this case based aircraft, flight schools, population, and climate) explain the variation of the dependent variable (in this case the OPS).

Once more, residual plots are used by statisticians to assess if a regression model is a good fit to its data, and to examine the underlying statistical assumptions required for regression. The analysis of the residual plots (see Figure A-9) indicated that regression is invalid due to the violation of two required statistical assumptions described above that must be met in order to use regression. The two assumptions are constant variance (right half of the residual plots in Figure A-9) and non-normal residuals (left half of the residual plots in Figure A-9). Ideally, the normal probability plot will have red dots tracing over the blue line and the top right graph (Fitted Value vs. Residual) will appear to be scattered in random pattern, or sometimes thought of as birdshot. In this case, the red dots do not follow the line closely enough to be considered normally distributed (and the histogram below it reinforces this view). The variance is not believed to be constant as the red dots in the top right graph are scattered in a cone pattern, so that the variance moves from small to larger as the fitted value increases.

Table A-8. Supplemental statistics showing significance of each variable in the reduced model using OPS (operations).

p value=0.000

Predictor	Coef	SECoef	t	p
Constant	16535	4508	3.67	0.000
AvgBA	198.98	21.41	9.30	0.000
NFS	5174	1299	3.98	0.000
Pop Scaled	44.13	12.74	3.46	0.001
SE	14880	6604	2.25	0.025
SW	52389	10286	5.09	0.000

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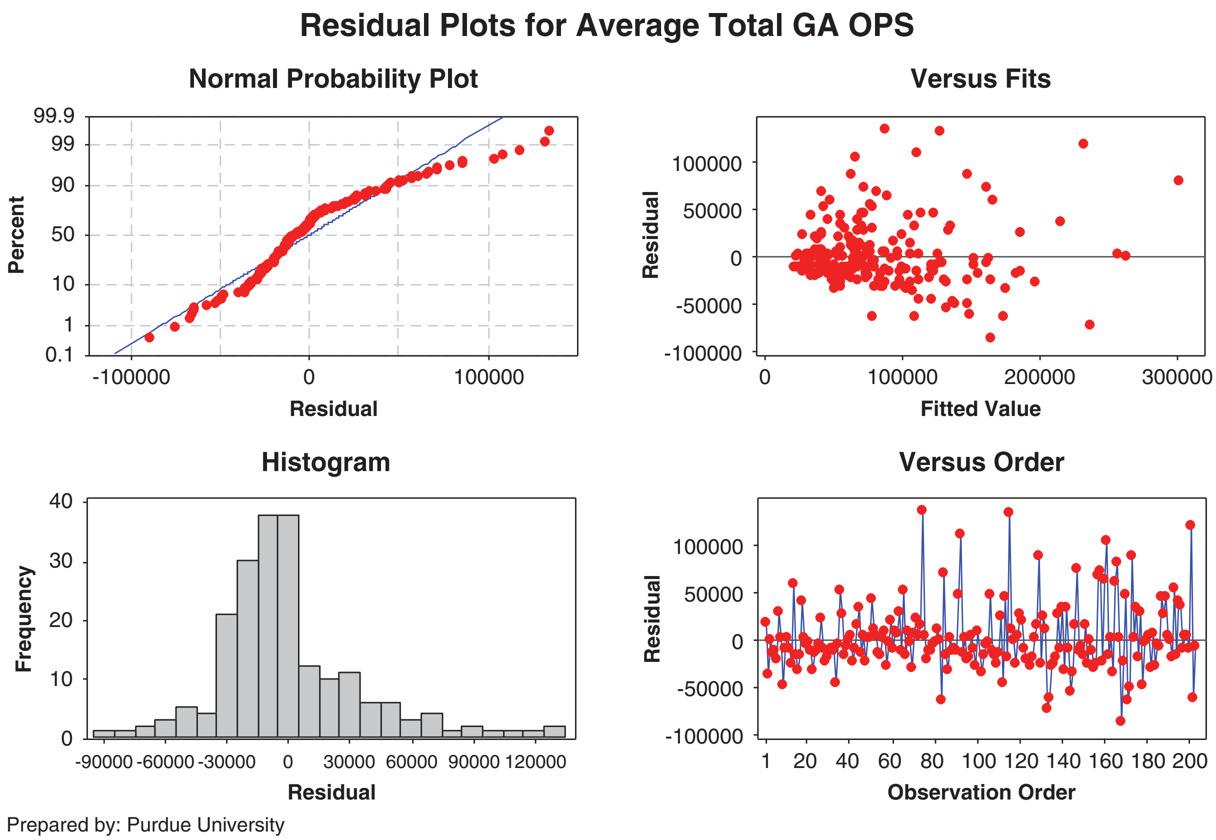

Figure A-9. Residual plots for operations (OPS) reduced model.

While this model may be more attractive for use in the field, it still is not recommended by the research team because it fails to meet the required statistical assumptions and it only explains approximately 65% of the variation in the data.

E. Overview of Models and Conclusions. Overall, the research team concludes that based on the study objectives and data, there were no practical and consistent OPBAs found or modeled at small, towered airports nationally or by climate region, even when considering the number of flight schools based at the airport. Therefore the research team cannot recommend an OPBA for estimating annual operations at non-towered airports using the variables identified in Table A-1. From all the models analyzed, only the full and reduced model using transformed data (i.e., log10AvgOPBA and log10BA) met the necessary assumptions for statistical validity. However, the two regression equations developed for them only accounted for about 50% of the behavior of annual operations—that is, they did not explain a high proportion of the variability in the airport operations data tested, and therefore are unable to predict airport operations with high certainty.

Table A-9 shows a comparison of three regression equations developed in this section. From the data, it can be shown that OPS are more accurately modeled than OPBA by comparing R-Sq(adj) for the models. The OPS model is dramatically better than the OPBA model (65.3% versus 27.5%), but neither meet all the required statistical assumptions for valid regression. As previously stated, similar results from other studies found that equations estimating OPS are more accurate than the equations estimating OPBA in estimation of activity at the non-towered airports.

The model developed using log10AvgOPBA meets the statistical assumptions and has an R-Sq(adj) of 50.4%, but calculations may be more difficult than non-transformed data. Additionally, this equation only explains approximately 50% of the variation of operations at 205 small, towered airports included in the STAD. Furthermore, the data used in this model development was from small, towered airports, so it assumes that small towered airports are an accurate representation of non-towered airports. Therefore, it may not satisfy the need for accurately estimating OPBA or OPS at non-towered airports.

Extrapolation Method to Estimate Annual Airport Operations

The counting of operations is time-consuming. Sampling methods use statistical methods to reduce the amount of time needed for counting samples and still provide accurate estimates. Estimating annual operations using sampling

Table A-9. Comparison of OPS, OPBA, and Log_{10}OPBA models (significant at p = 0.05).

Equation	R-square (adj)	Regression p-Value
OPS = 16535 + 199 AvgBA + 5174 NFS + 44.1 Pop Scaled + 14880 SE + 52389 SW	0.653	0.000
Easiest to use of all methods analyzed.		
Does not meet all required statistical assumptions.		
Not recommended.		
AvgOPBA = 572 - 1.11 AvgBA + 30.9 NFS + 0.613 Pop Scaled + 146 S + 214 SW + 177 RL	0.275	0.000
Does not meet all required statistical assumptions.		
Not recommended.		
log_{10}AvgOPBA = 3.94 - 0.621 log_{10}AvgBA + 0.000232 Pop Scaled + 0.0279 NFS - 0.0797 C + 0.0631 SE + 0.169 SW	0.504	0.000
Meets all required statistical assumptions.		
Calculations may be complex.		

Note: R-sq (adj) measures the proportionate reduction of total variation in Y associated with the use of the set of X variables.)
Prepared by: Purdue University

methods is typically done either by *statistical extrapolation* of sample operations counts or by *extrapolation using monthly/seasonal adjustment factors* developed from towered airport operations data. The process and results of testing these two methods using data from small, towered airports are described in Chapter 3 of this report. Additional details on the analysis are included below.

Statistical Extrapolation

The statistical extrapolation analysis presented in Chapter 3 was based on four sample sizes and timeframes. The sizes and timeframes are detailed here:

One week in each season: The FAA-APO-85-7 requires a minimum of two weeks per season to produce an estimate of the variation for each season. Therefore, the research team assumed the one week used in this exercise was representative of the whole season. While this method is not described in FAA-APO-85-7, it is a logical process to follow. For this exercise, actual daily operation data were collected for one randomly selected week in each season for each of 16 airports selected from the STAD. The random selection process was conducted separately for each airport. Accordingly, each airport may have different weeks included in the analysis. The one week sample from each season was multiplied by 13 to obtain a seasonal estimate of operations. [Note: Four seasons of 13 weeks each were assumed for each year (i.e., 13 weeks multiplied by four seasons equals 52 weeks).] The estimations from all four seasons were summed to estimate total annual aircraft operations.

Two weeks in each season: For this timeframe, actual daily operations data for two randomly selected weeks in each season for each of 16 airports selected from the STAD were used in the FAA Report No. FAA-APO-85-7 statistical estimation method. It was not required for the two randomly selected weeks to be consecutive. Again, the random selection process was conducted separately for each airport. The output consisted of total estimated annual operations for each airport.

One month in spring, summer, or fall: For this timeframe, actual daily operations data for one month of four consecutive weeks during spring, summer, or fall was collected for each of 16 airports selected from the STAD. Again, the random selection process was conducted separately for each airport. The operations data were used in FAA-APO 85-7 statistical estimation method and the output contained an estimate of operations for the respective season for each airport. To estimate annual operations, a seasonal distribution of operations is required by FAA-APO 85-7. A seasonal distribution is needed because aircraft operations are known to vary by season depending upon the airport's location. While the seasonal distribution is needed, it is not available if only one month in one season is sampled. Therefore, the monthly operations data were extrapolated into annual estimates using two methods of estimating the seasonal distribution. The first method assumed that each season contained an equal distribution of the year's total operations; so each season would account for 25% of the total annual operations. The second method for extrapolating the seasonal data into annual operations estimates used the distribution of operations from the "two weeks in each season" section.

One month in the winter: For this timeframe, actual operations data for one month of four consecutive weeks during winter were collected for each of the 16 airports selected from the STAD. Again, the random selection process was conducted separately for each airport. The operations data were used in FAA-APO 85-7 statistical estimation method and the output contained an estimate of operations for the winter season. To estimate annual operations, a seasonal distribution of operations is again required by FAA-APO 85-7. A seasonal distribution is needed because aircraft operations are known to vary by season depending upon the airport's location. However, like before, as seasonal variation it is not available because only one month in one season is sampled. Therefore, the winter season estimate of operations was extrapolated into annual estimates using two methods of estimating the seasonal distribution. The first method assumed that each season contained an equal distribution of the year's total operations so each season would account for 25% of the total annual operations. The second method for extrapolating the seasonal data into annual operations estimates used the distribution of operations from the "two weeks in each season" section.

Chapter 3 provides the results of this analysis. An example of using the FAA-APO-85-7 to estimate annual operations is provided in Appendix B.

Extrapolation Using Monthly/Seasonal Adjustment Factors from Towered Airports

This research exercise consisted of three elements: 1) calculate the percentage of operations that occur in each month for small, towered airports (i.e., STAD), and use these percentages to create monthly factors and seasonal factors for each region; 2) use those monthly and seasonal factors to extrapolate annual operations for two randomly selected airports in each NOAA Climatic Region; and 3) present and compare the accuracy levels of this extrapolation process using different sampling sizes and times of year.

Additional details of these elements are provided below.

1. Determine monthly and seasonal factors using all airports in the STAD. The first step in the analysis consisted of calculating monthly and seasonal factors for aircraft operations by region. To do this, the total operations for each month of 2010 were recorded from OPSNET for each airport in the STAD, and then monthly and seasonal factors for each region were calculated. To calculate each regional monthly factor, the total operations for each month were divided by the total yearly operations for all the airports in the region. (Note: Although there are nine NOAA Climatic Regions, the 205 airports in the STAD include airports that are in only eight NOAA regions. In addition to Alaska and Hawaii with only one airport each in the dataset, West North Central is not included because the dataset contains no airports for that region.) For seasonal factors, each season was assumed to be three months long. To calculate each region's seasonal factor, the total operations for the three months in each season were added and then were divided by the total yearly operations. Table A-10 includes the monthly and seasonal factors for each region calculated from all airports in the STAD. Table A-11 includes the number of airports in each region used in the STAD.

This analysis assumes all airports in a region have the same monthly and seasonal factors, that there are four seasons,

Table A-10. Monthly and seasonal factors per region using STAD airports.

Month	Northeast	Northwest	South	Southeast	Southwest	West	Central	East North Central
January	0.07	0.06	0.07	0.08	0.08	0.07	0.05	0.05
February	0.05	0.07	0.07	0.08	0.08	0.07	0.06	0.06
March	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09
April	0.09	0.09	0.09	0.10	0.08	0.08	0.09	0.08
May	0.10	0.10	0.09	0.09	0.08	0.09	0.09	0.09
June	0.10	0.10	0.09	0.08	0.09	0.09	0.09	0.10
July	0.10	0.10	0.09	0.08	0.08	0.09	0.10	0.12
August	0.10	0.10	0.09	0.08	0.08	0.09	0.10	0.10
September	0.08	0.09	0.09	0.08	0.09	0.09	0.09	0.09
October	0.08	0.08	0.09	0.09	0.09	0.08	0.10	0.09
November	0.08	0.05	0.08	0.08	0.08	0.08	0.08	0.07
December	0.06	0.05	0.07	0.07	0.08	0.07	0.06	0.05
Season								
Winter	0.20	0.22	0.23	0.24	0.25	0.23	0.20	0.20
Spring	0.28	0.29	0.27	0.27	0.25	0.26	0.27	0.27
Summer	0.28	0.30	0.26	0.23	0.25	0.27	0.29	0.31
Fall	0.23	0.19	0.24	0.25	0.24	0.23	0.24	0.22

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Table A-11. Number of airports in the dataset in each state and the number of airports used in the sample.

State	Region	# of Airports in State (STAD)
MI	East North Central	4
MN	East North Central	4
WI	East North Central	5
IA	East North Central	0
MO	Central	5
IL	Central	9
IN	Central	5
OH	Central	5
KY	Central	2
WV	Central	4
TN	Central	3
ME	Northeast	0
NH	Northeast	2
VT	Northeast	0
MA	Northeast	6
RI	Northeast	0
CT	Northeast	5
NY	Northeast	4
PA	Northeast	4
NJ	Northeast	3
DE	Northeast	1
MD	Northeast	3
OR	Northwest	4
WA	Northwest	4
ID	Northwest	0
KS	South	5
OK	South	6
TX	South	18
AR	South	3
LA	South	5
MS	South	4
FL	Southeast	24
AL	Southeast	1
GA	Southeast	6
SC	Southeast	3
NC	Southeast	3
VA	Southeast	1
UT	Southwest	2
CO	Southwest	3
AZ	Southwest	8
NM	Southwest	2
CA	West	26
NV	West	1
WY	West North Central	0
MT	West North Central	0
ND	West North Central	0
SD	West North Central	0
NE	West North Central	0
AK	Alaska	1
HI	Hawaii	1
	Total	205

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and each season has 13 weeks. To maintain seasonal representation and to get all 12 months into four seasons for that calendar year, the seasons were identified as winter (January–March), spring (April–June), summer (July–September), and fall (October–December). In this way, the 2010 annual operations could be compared to the estimates of annual operations developed using seasonal factors. It is important to note, however, that in practice, climatic conditions may vary widely between regions and even within each region.

2. Extrapolate annual operations using the monthly and seasonal factors from the STAD airports. The next step for this research was to extrapolate annual operations using the monthly and seasonal factors (shown in Table A-10). A group of small, towered airports was selected for this procedure because both actual operations and extrapolated operations are compared to determine the accuracy of the process. Two STAD airports from each of eight NOAA climatic regions were randomly selected for use in the test, using a random numbers table. This resulted in 16 small towered test airports. (Note: These are the same airports included in the statistical extrapolation analysis presented earlier.) The airport codes for these 16 airports are listed in Table A-12. As in the other analyses, Alaska and Hawaii were excluded from this analysis because there is only one airport in each of these regions in the dataset. The West North Central region is also excluded from this task because there are no airports from this region that meet the criteria to be included in the STAD dataset.

Four sampling scenarios were used to extrapolate annual operations estimates:

A. One week in each season
B. Two weeks in each season
C. One month (either spring, summer or fall)
D. One month in winter

Each sampling scenario is explained in the following paragraphs. A summary of the analysis is shown in Table A-12. Again, the same 16 airports and the same time periods used in the statistical extrapolation described in Chapter 3 were used to estimate total yearly operations in this section. (See Table A-12 for the airport codes.)

A. One week in each season: For each of the 16 test airports, one week of OPSNET data for each season were collected. The weekly data were multiplied by 4.3 weeks per month to obtain an estimate of monthly operations for that specific month. Using the monthly and seasonal factors developed for that region, an estimate of annual operations was calculated. (See Table A-12 for annual estimates and Table A-10 for monthly and seasonal factors.)

Table A-12. Estimates of annual operations using monthly/seasonal extrapolation and four sampling scenarios.

Airport	Region	1 Week each Season	2 Weeks each Season	1 Month Spring, Summer, or Fall	Season Selected	1 Month Winter	Month in Winter Selected	Actual Operations (OPSNET)	1 Week each Season	2 Weeks each Season	1 Month Spring, Summer, or Fall	1 Month Winter
CPS	Central	113,764	126,605	97,938	Fall	126,909	Feb.	111,620	2%	13%	-12%	14%
DPA	Central	101,692	82,865	72,858	Spring	72,360	Mar.	89,989	13%	-8%	-19%	-20%
ANE	East North Central	80,256	78,920	79,473	Spring	78,928	Feb. and Mar.	79,603	1%	-1%	0%	-1%
MIC	East North Central	30,029	40,558	35,739	Summer	45,481	Feb. and Mar.	44,229	-32%	-8%	-19%	3%
ASH	Northeast	68,659	82,627	57,111	Fall	61,563	Jan.	74,111	-7%	11%	-23%	-17%
RME	Northeast	49,531	47,908	35,943	Summer	73,128	Feb.	47,790	4%	0%	-25%	53%
PDT	West	12,106	12,440	14,016	Fall	13,034	Feb. and Mar.	12,994	-7%	-4%	8%	0%
TIW	West	48,266	48,837	42,199	Spring	54,603	Jan. and Feb.	53,960	-11%	-9%	-22%	1%
FTW	South	83,370	81,069	72,014	Fall	91,839	Feb.	78,499	6%	3%	-8%	17%
GLS	South	28,646	33,290	30,301	Summer	27,556	Feb. and Mar.	31,652	-9%	5%	-4%	-13%
HEF	Southeast	81,030	100,971	92,411	Summer	80,306	Feb. and Mar.	92,394	-12%	9%	0%	-13%
OPF	Southeast	94,524	96,819	82,483	Spring	101,658	Jan. and Feb.	98,708	-4%	-2%	-16%	3%
BJC	Southwest	115,364	113,461	114,742	Fall	106,536	Jan. and Feb.	120,363	-4%	-6%	-5%	-11%
HOB	Southwest	14,941	14,233	16,914	Spring	14,974	Feb. and Mar.	16,637	-10%	-14%	2%	-10%
CMA	West	151,100	148,393	165,637	Spring	174,536	Feb. and Mar.	146,863	3%	1%	13%	19%
TOA	West	118,025	79,103	85,326	Summer	115,623	Mar.	106,438	11%	-26%	-20%	9%

Note: Positive % differences indicate that the actual annual operations are larger than the estimated annual operations.
Negative % differences indicate that the actual annual operations are smaller than the estimated annual operations.
Prepared by: Purdue University

B. Two weeks in each season: For each of the 16 test airports, two weeks of OPSNET data for each season were collected. The weekly data were averaged and multiplied by 4.3 weeks per month to obtain an estimate of monthly operations for that specific month. Using the monthly and seasonal factors developed for that region, an estimate of annual operations was calculated. (See Table A-12 for annual estimates and Table A-10 for monthly and seasonal factors.)
C. One month in spring, summer, or fall: For each of the 16 test airports, one month (four consecutive weeks) of OPSNET data for one season were collected. The monthly data were divided by the monthly factor for that month to estimate the annual operations. (See Table A-12 for annual estimates and Table A-10 for monthly and seasonal factors.)
D. One month in winter: For each of the 16 test airports, one month (four consecutive weeks) of OPSNET data for the winter season were collected. The monthly data were divided by the monthly factor for that month to estimate the annual operations. (See Table A-12 for annual estimates and Table A-10 for monthly and seasonal factors.)

3. Compare actual operations to the estimates. The final task included a comparison of the actual operations of the 16 test airports to the estimated operations. The percent difference between each test airport's estimated annual operations and the actual OPSNET annual operations were calculated and are shown in Table A-12. A summary of the percent differences between OPSNET data and the extrapolated estimates is shown in Table A-13. The estimates of percent differences are summarized by listing the average, the average of the absolute values, highest, the lowest, and the range for each of the four sampling scenarios.

Discussion and Additional Analyses. As may be seen in Table A-13, estimates made using the sampling scenario of two weeks per season provided an estimate closest to actual operations for the test airports, on average. Estimates made using the sampling scenario of one month winter were the second closest to actual operations, on average. The ranges for estimated operations for the sampling scenarios of 2 weeks per season and 1 month (spring, summer or fall) were the closest to actual operations in terms of range of the percent differences.

When reviewing the data in Tables A-12 and A-13, it is not immediately apparent if there are statistical differences in the results due to the sampling method (e.g., one week per season, two weeks per season, etc.). Box plots are another way to represent the data from Table A-13. Box plots split the data into quartiles with the box consisting of the second and third quartile and a horizontal line drawn between the two quartiles. This line is the median of the data set. Vertical lines extending above and/or below the box to show the smallest and largest quartiles, and outliers are shown as asterisks. The first boxplot (Figure A-10) summarizes the data based on sampling scenario. By observation, the sampling method of one month in the winter appears to have a wider standard deviation than the other methods. This finding is consistent with the range data shown in Table A-13.

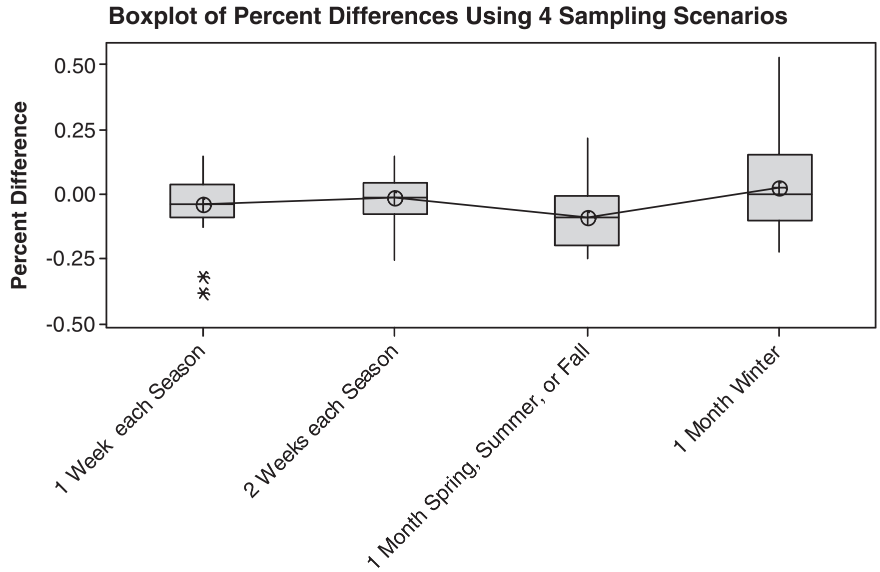
The next test was to determine which of the sampling methods were statistically different from the others. The one-way ANOVA for percent differences in annual operations was conducted for sampling scenario and the results reported in Table A-14. The one-way ANOVA analysis indicates which sampling methods are different from other sampling methods, in terms of statistically significant percent differences. The p-value for sampling scenario (one week in each season; two weeks in each season; one month spring, summer or fall; and one month winter) is 0.009 and is smaller than the critical alpha of 0.05. This evidence leads the research team to conclude that there is at least one sampling method that is different from the others.

The Tukey test is performed after an ANOVA and is used to determine which sampling scenarios have significant differences from each other. Based on the Tukey Analysis shown in Table A-15, the percent differences from the actual

Table A-13. Summary of the percent difference between estimates and OPSNET annual operations.

% Difference from OPSNET Annual Operations	1 Week each Season	2 Weeks each Season	1 Month Spring, Summer, or Fall	1 Month Winter
Average of real values	4%	2%	9%	2%
Average of absolute values	9%	8%	12%	13%
Highest	13%	13%	13%	53%
Lowest	-32%	-26%	-25%	-20%
Range	45%	39%	38%	73%

Prepared by: Purdue University



Prepared by: Purdue University

Figure A-10. Box plot of sampling methods: 1 week each season; 2 weeks each season; 1 month spring, summer, or fall; and 1 month winter.

operations data for the sampling method using one month in the winter are different from the sampling method using one month in the spring, summer, or fall. The 95% confidence interval for this difference between the two methods is 2.53% to 19.57%, with a mean of 11.05%. While the averages (means of the percent differences) have different values in Table A-15, the relatively large standard deviation makes the detection of a statistical difference difficult. In addition to the significant difference just described, the Tukey Analysis results show that there is not enough evidence to conclude that a significant difference in results occur when comparing 1 week each season, 2 weeks each season, and 1 month

Table A-14. One-way ANOVA for sampling scenario.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F statistic	P value
Sampling Scenario	3	0.2075	0.0692	4.03	0.009
Error	124	2.1260	0.0171		
Total	127	2.3336			

Note: S = 0.1309 R-Sq = 8.89% R-Sq(adj) = 6.69%
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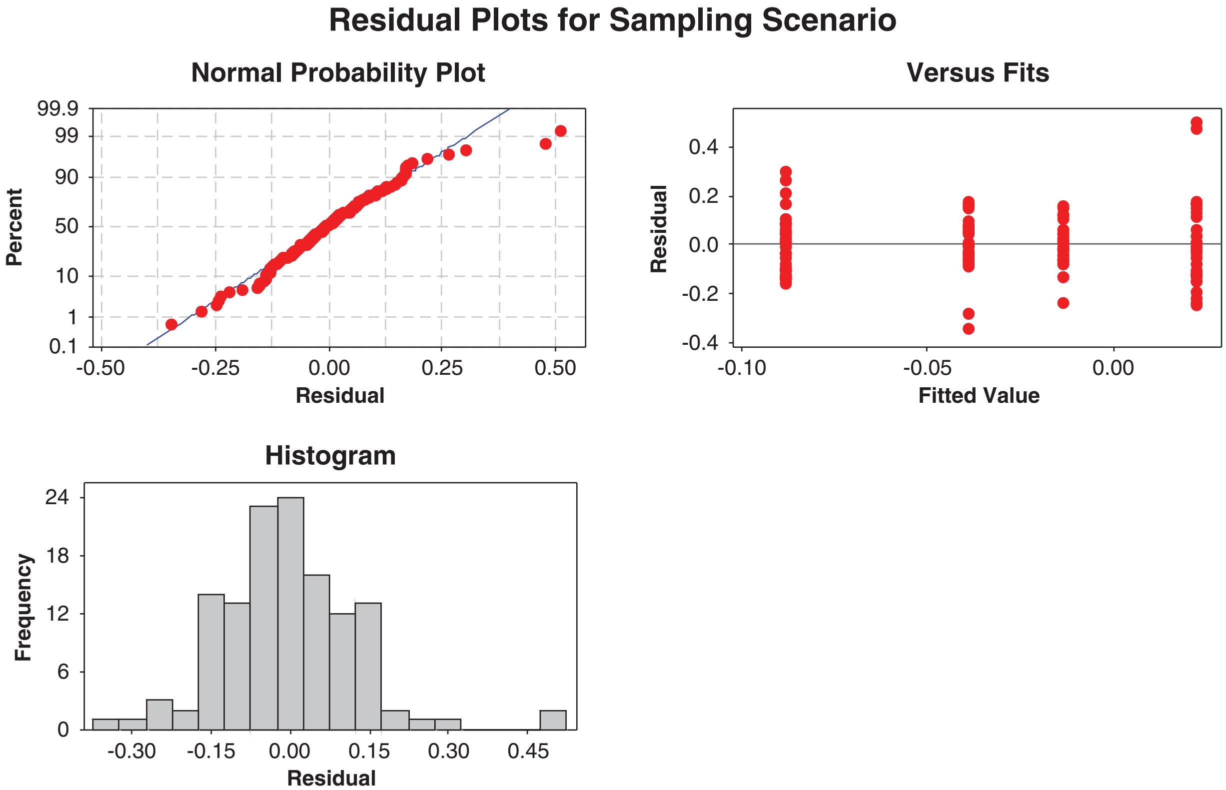
Table A-15. Data summary and Tukey Analysis.

Sampling Scenario	N	Mean of the % Differences	Standard Deviation	Tukey Grouping
1 Week each Season	32	-0.0393	0.1127	A B
2 Weeks each Season	32	-0.0134	0.0895	A B
1 Month Spring, Summer, or Fall	32	-0.0884	0.1234	B
1 Month Winter	32	0.0220	0.1806	A

Notes: Pooled StDev = 0.1309. Means that do not share a letter are significantly different.
Tukey Comparison 95% Confidence Level of the difference between Sampling Scenario using 1 Month Spring, Summer, or Fall subtracted and Sampling Scenario using 1 Month Winter:

Lower	Center	Upper
0.0253	0.1105	0.1957

Individual confidence level = 98.96%.
Prepared by: Purdue University



Prepared by: Purdue University

Figure A-11. Residual plots for sampling scenario (one-way ANOVA).

winter (shown as Tukey Grouping A in Table A-15). Moreover, the Tukey Analysis results show that there is not enough evidence to conclude that a significant difference in results occur when comparing 1 week each season, 2 weeks each season, and 1 month spring, summer, or fall (shown as Tukey Grouping B in Table A-15).

The residual plots in Figure A-11 indicate that the assumptions for ANOVA are met and the analysis may be used with confidence. Based on observation of the residual plots, the ANOVA analysis appears valid. Residual plots are used to make conclusions about the ANOVA assumptions regarding normality of the residuals and constant variance of the residuals.

APPENDIX B

Example of Estimating Operations from Sample Counts Using Forms from FAA-APO-85-7, *Statistical Sampling of Aircraft Operations at Non-Towered Airports*

Using the attached forms, follow these steps to estimate annual operations from sample counts. These forms are reproduced from FAA-APO-85-7, *Statistical Sampling of Aircraft Operations at Non-Towered Airports*. The following example is also taken directly from the FAA-APO-85-7. While the forms may appear intimidating, all the mathematical functions can be completed on a simple calculator and include calculations no harder than addition, subtraction, multiplication, division, and square root.

STEP 1
Daily Operations

Using **Form 1** as a worksheet, the total daily operations are tallied. For a sample that includes 2 weeks per season, 8 Form 1s would be needed.

The total daily operations will be transferred to Form 2, Weekly Data, Column B.

8 Form 1s

STEP 2
Weekly Operations

Using **Form 2** as a worksheet, the number of weekly total operations is calculated. Again, there would be Form 2 for each Form 1 completed (8 total).

The data is then transferred to **Form 3**.

Transferred to 8 Form 2s

STEP 3
Average Daily Operations for Each Week

Still using **Form 2** as a worksheet, the average daily operations for each week are calculated.

The data from the two Form 2s for each season are transferred to **Form 3** resulting in 4 Form 3s.

Transferred to 4 Form 3s

STEP 4
Average Daily Operations for Each Season

In this step, **Form 3** is used to find average daily operations for each season and to calculate additional numbers that will be used on **Form 4**.

STEP 5
Total Operations for Each Season

Still using **Form 3**, the number of total operations for each season is calculated and transferred to **Form 4**.

STEP 6
Total Annual Operations Estimate

Using **Form 4**, the sample data is expanded to estimate total annual operations and to calculate additional measures.

Transferred to 1 Form 4

STEP 7
Confidence Interval and Sampling Error

Still on **Form 4**, additional measures can be calculated, such as precision of the estimate of annual operations, confidence interval and percent sample error.

INSTRUCTIONS FOR FORM 1 (Reproduced from FAA-APO-85-7)

DAILY COUNTS

This is an example of a completed Form 1. Two week samples in each season will produce eight Form 1s. The purpose of Form 1 is to serve as a worksheet to tally or tabulate the sample data and to obtain total daily operations. These samples may be from direct observation of operations or through an indirect sample counting method. You may proceed directly to Form 2 if daily operations are given directly from an aircraft traffic counter and do not need to be tallied.

In the boxes at the top of the form fill in the name of the airport sampled and the season number and week number from which the data were collected. Weeks sampled are numbered consecutively throughout the year. Fill in the date of each of the seven days sampled.

Day 1 - Tabulate the number of operations counted during each hour in Day 1. Add the hourly operations. Enter the answer in the total box at the end of the column for Day 1.

Day 2-7 - Repeat the tabulation of hourly operations for each day. Add each column of hourly operations to obtain total operations for each day. Daily operations will be transferred to Form 2, Weekly Data, Column B. One Form 2 will be needed for each Form 1.

Example

FORM 1

Airport Name		Tri-City State	
Season	1	Week	1

Day	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Time of Day	7/21/2014	7/22/2014	7/23/2014	7/24/2014	7/25/2014	7/26/2014	7/27/2014
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							2
8:00 AM							4
9:00 AM							
10:00 AM	2			2	4		
11:00 AM			2		2		
12:00 PM	6		2	2	2	2	2
1:00 PM	2				2	2	
2:00 PM	10		2	2			2
3:00 PM	2		2				2
4:00 PM	6	4					
5:00 PM		2					2
6:00 PM							
7:00 PM							
8:00 PM							
9:00 PM							
10:00 PM							
11:00 PM							
TOTALS	28	6	8	6	10	4	14

FORM 1

Airport Name		Tri-City State	
Season	1	Week	2

Day	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Time of Day	9/16/2014	9/17/2014	9/18/2014	9/19/2014	9/20/2014	9/21/2014	9/22/2014
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM							
9:00 AM				2			
10:00 AM			2				
11:00 AM							
12:00 PM	4			10			
1:00 PM	2	2					6
2:00 PM							
3:00 PM						4	
4:00 PM							
5:00 PM						2	
6:00 PM							
7:00 PM	2						
8:00 PM							
9:00 PM							
10:00 PM							
11:00 PM							
TOTALS	8	2	2	12	0	6	6

FORM 1

Airport Name	
Season	Week

Day	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Time of Day							
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM							
9:00 AM							
10:00 AM							
11:00 AM							
12:00 PM							
1:00 PM							
2:00 PM							
3:00 PM							
4:00 PM							
5:00 PM							
6:00 PM							
7:00 PM							
8:00 PM							
9:00 PM							
10:00 PM							
11:00 PM							
TOTALS							

INSTRUCTIONS FOR FORM 2 (Reproduced from FAA-APO-85-7)

WEEKLY DATA

The purpose of Form 2 is to calculate total operations and average daily operations for each week, and other numbers that will be used on Form 3. There will be one Form 2 produced for each Form 1 completed.

In the boxes at the top of Form 2 fill in the name of the airport sampled and the season number and week number from which the data were collected. If you have two weeks of sampling, then you will need two of these forms.

Column A	Fill in the date of each day sampled on the lines in Column A.
Column B	Fill in the number of operations counted on each date on the lines in Column B. Operations for each date are obtained from the bottom row of Form 1 if daily observations are taken.
Box C	Add the values in Column B. Enter the answer, total weekly operations, in Box C.
Box D	Divide the value in Box C by the number of days counted in the week (normally 7). Enter the answer, average daily operations, in Box D, This number will be used in Column E and transferred to Form 3, Column A.
Column E	Subtract the value in Box D from the value on line 'in Column B. Enter the answer on line 1 of Column E. Repeat this step, subtracting D from each value in Column B.
Column F	Square each value in Column E and enter the answers in Column F. (All squared numbers will be positive.)
Box G	Add the values in Column F. Enter the answer in Box G, This number will be transferred to Form 3, Column K.

Example
FORM 2

Airport Name	Tri-City State		
Season	1	Week	1

Multiply the number directly to the left in column E by itself

Columns

	A	B	E	F
Day	DATE	Daily Operations	Column B Minus Box D	Column E Squared
1	7/21/2014	28	17.14	293.78
2	7/22/2014	6	-4.86	23.62
3	7/23/2014	8	-2.86	8.18
4	7/24/2014	6	-4.86	23.62
5	7/25/2014	10	-0.86	0.74
6	7/26/2014	4	-6.86	47.06
7	7/27/2014	14	3.14	9.86
	C = TOTAL WEEKLY OPERATIONS	76	G = Sum of Column F	406.86

Box D

D = AVERAGE DAILY OPERATIONS	10.86

Box G

Box C = The sum of Colum B

D = C ÷ by number of days counted

FORM 2

Airport Name			
Season		Week	

	A	B	E	F
Day	DATE	Daily Operations	Column B minus Box D	Column E Squared
1				
2				
3				
4				
5				
6				
7				
	C = TOTAL WEEKLY OPERATIONS		G = Sum of Column F	

D = AVERAGE DAILY OPERATIONS	

INSTRUCTIONS FOR FORM 3 (Reproduced from FAA-APO-85-7)

SEASONAL DATA

The purpose of Form 3 is to find average daily operations for each season and to calculate numbers that will be used on Form 4. Two week samples in each season will produce four Form 3s—one for each season.

In the boxes at the top of the Form, fill in the name of the airport sampled. Fill in the season from which the sample data were collected. Also fill in the season size (N = total number of weeks in the season), the sample size (n = number of weeks sampled in the season), and the week size (M = number of days [normally 7]).

(Note: Form 3 assumes a cluster of 7 days (one week) is sampled, and therefore N, n, and M are based on weeks. If a cluster of days less than one week or greater than one week is sampled, refer to FAA-APO-8507.)

Column A	Fill in the average daily operations per week on the lines in Column A. Average daily operations per week are transferred from Form 2. Box D. Column A may have 2 or more lines depending on the number of weeks sampled.
Box B	Add the values in Column A and enter the answer in Box B.
Box C	Divide the value in Box B by n (find n in box at top of Form 3). Enter the answer in Box C. This number will be used in Column D and transferred to Form 4, Column H.
Column D	Subtract the value in Box C from the value on line 1 in Column A. Enter the answer on line 1 in Column D. Repeat this step for each value in Column A.
Column E	Square each value in Column D and enter the answer (always a positive number) in Column E.
Box F	Add the values in Column E and enter the answer in Box F.
Box G	Subtract 1 from n (find n in box at top of Form 3) and enter the answer in Box G.
Box H	Divide the value in Box F by the value in Box G and enter the answer in Box H.
Box I	Subtract 1 from N (find N in box at top of Form 3) and enter the answer in Box I.
Box J	Multiply the value in Box H by the value in Box I. Enter the answer in Box J.
Column K	Enter the value from Form 2, Box G for each week on the appropriate line in Column K.
Box L	Add the values in Column K and enter the answer in Box L.
Box P	Subtract 1 from M (find M in box at top of Form 3). Multiply the value (M-1) by n and enter the answer in Box P.
Box Q	Divide the value in Box L by the value in Box P and enter the answer in Box Q.
Box R	Subtract 1 from M. Multiply the value (M-I) by N and enter the answer in Box R.
Box S	Multiply the value in Box Q by the value in Box R and enter the answer in Box S.
Box T	Add the values in Box J and Box S and enter the answer in Box T.
Box U	Multiply N times M and then subtract 1. Enter the answer in Box U.
Box V	Divide the value in Box T by the value in Box U and enter the answer in Box V. This value is also transferred to Form 4, Column K.

FORM 3

Airport Name	Tri-City State
Season	1

TOTAL WEEKS IN SEASON = N	13
WEEKS SAMPLED IN SEASON = n	2
DAYS IN WEEK = M	7

Columns

	A	D	E	K
Week	Average Daily Operations (Transfer Box D from Form 2)	Column A minus Box C	Column D Squared	Transfer Box G from Form 2 (Sum of column F on Form 2)
1	10.86	2.86	8.18	406.86
2	5.14	-2.86	8.18	102.86
3				
4				

Refer to Form 2 for this information

B = Sum of Column A	16.00
C = Average Daily Operations for Season	8.00

Box F, Box G, Box H, etc.

F= Sum Col. E	16.36
G = n - 1	1
H = F ÷ G	16.36
I = N - 1	12
J = H x I	196.31

L = Sum of Column K	509.72
P = n x (M - 1)	12
Q = L ÷ P	42.48
R = N x (M-1)	78
S = Q x R	3313.18
T = J + S	3509.49
U = (N x M) - 1	90
V = T ÷ U	38.99

FORM 3

Airport Name	
Season	

TOTAL WEEKS IN SEASON = N	
WEEKS SAMPLED IN SEASON = n	
DAYS IN WEEK = M	

	A	D	E	K
Week	Average Daily Operations (Transfer Box D from Form 2)	Column A minus Box C	Column D Squared	Transfer Box G from Form 2 (Sum of Column F on Form 2)
1				
2				
3				
4				

B = Sum of Column A		F= Sum Col. E		L = Sum of Column K	
		G = n - 1		P = n x (M - 1)	
		H = F ÷ G		Q = L ÷ P	
C = Average Daily Operations for Season		I = N - 1		R = N x (M-1)	
		J = H x I		S = Q x R	
				T = J + S	
				U = (N x M) - 1	
				V = T ÷ U	

INSTRUCTIONS FOR FORM 4 (Reproduced from FAA-APO-85-7)

ANNUAL ESTIMATES

The purpose of Form 4 is to expand the sample data to estimate total annual operations and to calculate measures of precision of the estimate of annual operations, including the confidence interval and the percent sampling error.

In the boxes at the top of Form 4 fill in the name of the airport sampled and the period of the sample.

Column A	Fill in the total number of days in each season D, on the lines in Column A. Use the actual number of calendar days, not number of weeks, N, times 7 days. (If data is not stratified by season, only one line will be used.)
Column B	Square each value of D and enter the answer in Column B.
Column C	Fill in the number of days sampled, d, in each season on the lines in Column C. (When sampling 2 weeks in each season, D = 14.)
Column D	For each season divide D^2 in Column B by d in Column C and enter the answer in Column D.
Column E	For each season divide d in Column C by D in Column A and enter the answer in Column E.
Column F	Subtract d÷D in Column E from 1 and enter the answer in Column F. Transfer the value of D for each season from Column A to the appropriate line in Column G.
Column H	Fill in the average daily operations for each season on the lines in Column H. Average daily operations are obtained from Form 3, Box C.
Column I	For each season, multiply D in Column G by average daily operations in Column H. Enter the answer on the appropriate line in Column I.
Box J	Add the values in Column I and enter the answer, annual operations, in Box J.
Column K	Fill in the value from Form 3, Box V for each season on the appropriate line in Column K.
Column L	For each season, transfer the values for $D^2 \div d$ from Column D to Column L.
Column M	For each season multiply the value in Column K by $D^2 \div d$ in Column L, Enter the answer in Column M.
Column N	For each season transfer the value 1 - (d ÷ D) from Column F to Column N.
Column O	For each season multiply the value in Column M by 1 - (d ÷ D) in Column N and enter the answer in Column O. This value is the variance of operations in each season.
Box P	Add the values in Column O. Enter the answer, the variance of estimated annual operations, in Box P.
Box Q	Take the square root of the value in Box P and enter the answer in Box Q. (The symbol on a calculator for square root is √)
Box R	Find the appropriate t-value from the chart, to the right based on the value (d-1). (Find d from Column C, then subtract 1.) Use the lowest value of d in Column C. Enter the t-value in Box . (Example t-value if d-1=13, then t=2.1)
Box S	Multiply the value in Box Q by the t-value in Box . Enter the answer in Box S. This is the percent confidence interval or range of the estimated operations. It is a measure of the precision of the annual operations estimate.
Box T	Divide the value in Box S by the value in Box J and multiply by 1 . Enter the answer in Box T. This is the percent sampling error, which is also a measure of the precision of the annual operations estimate.

Example
FORM 4

Airport Name	Tri-City State

Columns

Season	A D = Total Days in Season	B D^2	C d = number of days sampled	D $D^2 \div d$	E d ÷ D	F 1 - (d ÷ D)
1	92	8464	14	604.57	0.15	0.85
2	92	8464	14	604.57	0.15	0.85
3	91	8281	14	591.5	0.15	0.85
4	91	8281	14	591.5	0.15	0.85

Columns

Season	G D (Transferred from Column A above)	H Average (Transfer Box C from Form 3)	I Total (Column G x Column H)
1	92	8	736
2	92	4.57	420.44
3	91	6.76	615.16
4	91	5.52	502.32
		J = Annual Operations	2274

Season	K Transfer Box V from Form 3	L $D^2 \div d$ (Transfer from Column D above)	M Column K x Column L	N 1 - (d ÷ D) (Transfer from Column F above)	O Column M x Column N
1	39	604.57	23578.23	0.85	20041.5
2	18.85	604.57	11396.15	0.85	9686.73
3	99.17	591.5	58659.06	0.85	49860.2
4	21.68	591.5	12823.72	0.85	10900.16

P = Sum of Column O (This is the Variance of Operations)	40488.59
Q = square root of P	300.81
R = t-value for d-1 (see t-value chart to right) Use the lowest value for d found in Column C. Enter corresponding amount for t	2.16
S = Q x R (This is the 95% Confidence Interval or range of the estimated operations. It is a measure of the precision of the annual operations estimate.)	650
T = (S ÷ J) x 100 (Percent Sampling error)	28.6

t-value Chart

If d - 1 =	then t =
3	3.182
4	2.776
5	2.571
6	2.447
7	2.365
8	2.306
9	2.262
10	2.228
11	2.201
12	2.179
13	2.160
14	2.145
15	2.131
16	2.120
17	2.110
18	2.101
19	2.093
20	2.066
30	2.042
40	2.021
50	2.009
60	2.000
80	1.990

FORM 4

Airport Name	

	A	B	C	D	E	F
Season	D = Total Days in Season	D^2	d = number of days sampled	$D^2 \div d$	d ÷ D	1 - (d ÷ D)
1						
2						
3						
4						

	G	H	I
Season	D (Transfer from Column A above)	Average (Transfer Box C from Form 3)	Total (Column G x Column H)
1			
2			
3			
4			
		J = Annual Operations	

	K	L	M	N	O
Season	Transfer Box V from Form 3	$D^2 \div d$ (Transfer from Column D above)	Column K x Column L	1 - (d ÷ D) (Transfer from Column F above)	Column M x Column N
1					
2					
3					
4					

P = Sum of Column O (This is the Variance of Operations)	
Q = square root of P	
R = t-value for d-1 (see t-value chart to right) Use the lowest value for d found in Column C. Enter corresponding amount for t	
S = Q x R (This is the 95% Confidence Interval or range of the estimated operations. It is a measure of the precision of the annual operations estimate.)	
T = (S ÷ J) x 100 (Percent Sampling error)	

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14	2.145
15	2.131
16	2.120
17	2.110
18	2.101
19	2.093
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40	2.021
50	2.009
60	2.000
80	1.990

APPENDIX C

FAA-APO-85-7, *Statistical Sampling of Aircraft Operations at Non-Towered Airports*

STATISTICAL SAMPLING OF AIRCRAFT OPERATIONS AT NON-TOWERED AIRPORTS

Prepared by
Oregon Department of Transportation
Aeronautics Division

Performed Under Contract For
Federal Aviation Administration
Aviation Policy and Plans

February, 1985

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16. Abstract

The purpose of this handbook is to provide a statistically sound method of estimating aircraft operations at non-towered airports from sampling counts. The handbook is written for planners, engineers, airport operators responsible for airport planning, and persons that collect data for FAA Airport Master Records (Form 5010.1). Many of these users will be familiar with general aviation airports, but not necessarily with statistical methods.

Accurate information on aircraft activity at non-towered airports is a major need of airport owners and operators as well as planners and administrators charged with the planning and development of the airport system. Unlike towered airports, where air traffic controllers keep constant tallies of activity, most non-towered airports have no accurate record of usage.

Obtaining accurate aircraft activity counts will provide a variety of benefits. Investment decisions can be made with more confidence if benefit-cost analysis is based on accurate information about use of the facility. Design criteria, which may have a significant impact on development and operating costs, can be more efficiently applied. Even when decisions are based on forecasts rather than present circumstances, accurate base data is necessary to make accurate forecasts of activity.

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STATISTICAL SAMPLING OF AIRCRAFT OPERATIONS AT NON-TOWERED AIRPORTS

Mark Ford
Rosalyn Shirack
Oregon Department of Transportation
Aeronautics Division

Performed Under Contract For
Federal Aviation Administration
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INTRODUCTION

Accurate information on aircraft activity at non-towered airports is a major need of airport owners and operators as well as planners and administrators charged with the planning and development of the airport system. Unlike towered airports, where air traffic controllers keep constant tallies of activity, most non-towered airports have no accurate record of usage.

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Sampling and Estimating Procedures

Methods of counting aircraft operations fall into two general categories: visual methods, which require the observer to be physically present at the airport; and mechanical methods, such as acoustical and pnuematic tube counters, which collect information without requiring the full-time presence of an observer. All methods of counting aircraft operations, both visual and mechanical, have usually been found to be too expensive to permit continuous counts over long periods. The alternative is to use sample counts to estimate activity over any given period.

Estimating procedures generally fall into four categories. The first is based on the recollections of fixed base operators, managers or others associated with a particular airport. When compared to actual observations these estimates have usually been found to be inaccurate, either because it is the busy periods that stick in the minds of those making the estimates, or because a significant number of operations, particularly local operations, are unnoticed. For example, operations estimates on the FAA 5010-1 form are usually derived from recollections of annual activity. Comparisons of operations estimates based on sample data to operations estimates reported on 5010-1 forms for a number of Northwest airports in 1981 and 1983 indicate that overestimates of 80 percent or more on 5010-1 forms were not uncommon.

A second type of estimating procedure relies on a previously established relationship between aircraft operations and an independent factor. For example, a ratio of operations per based aircraft is often used to estimate operations. This method is sometimes useful to make system-wide estimates when no other information is available. However, the system-wide ratio applied to any individual airport within the system may be extremely inaccurate. Also, the procedure assumes that accurate operations estimates are available to develop the ratio of operations per based aircraft.

A third type of estimating procedure relies on an accurate measure of operations over a brief sample period. These sample counts are used in conjunction with independent data, such as operations from a tower airport, to estimate non-towered operations throughout the remainder of the year. The reliability of these estimates is questionable because there is no way to determine in advance whether or not the independent data (such as tower operations) are really related to operations at the non-towered airport. For example, a study comparing 1983-84 operations data between four towered and seven non-towered airports indicates tower operations data do not provide reliable estimates of operations at non-towered airports.[1] Similar results were obtained from a 1981 study of 9 towered and 24 non-towered airports in the Northwest.[2]

The fourth and most reliable method of estimating aircraft activity is based on statistical sampling of aircraft operations.

Statistical Sampling

Statistical sampling is a method whereby all operations have an equal chance of being sampled. For this reason it is often called random sampling. Benefits of statistical sampling for estimating aircraft operations may be summarized into four categories:

1. It ensures sampled operations are representative of operations throughout the year.
2. It provides an estimate of operations during a given period without the costly counting of all aircraft activity;
3. It allows estimates of operations to be made with a known degree of precision; and
4. It allows resources to be used efficiently by relating size (and cost) of the sample to the level of precision required.

[1]Unpublished study of towered and non-towered airport operations data; Oregon Department of Transportation, 1984.

[2]Aircraft Activity Counter Demonstration Project, Final Report, Aeronautics Division, Oregon Department of Transportation, 1982.

Statistical sampling differs from other methods of sampling in that it relies on the random choice of operations. This procedure ensures the sampled operations are representative of operations throughout the year. It prevents known or unknown factors from affecting the sample and skewing the resulting estimate. For example, if aircraft operations were sampled only on sunny days, the results would likely be an overestimate of total operations. By avoiding rainy days, the sampler would not get a representative sample of the entire year. Random sampling ensures that operations are sampled independently of the sampler's preferences and biases.

With respect to the second point, reliable information about aircraft operations likely would not be available without the cost savings of a sample estimate. The cost of a visual count of all operations 365 days a year, 24 hours a day is prohibitive. The capital and maintenance costs of a mechanical count of all operations for a year is also very high.

An estimate of annual operations based on a sample of operations is much less costly than a complete count of annual operations. Sample data is collected using the same techniques, whether visual or mechanical, as would be used for a complete count of operations. However, most samples are based on 10% or less of the operations. Therefore, even allowing for some additional costs associated with sample planning and estimating, the cost of collecting sample operations data is much less than the cost of a full count.

Only statistical sampling provides both an estimate and a measure of the precision of the estimate. Other types of sampling can provide an estimate, but there is no valid way to determine how precise the estimate is. Precision of the estimate is as important as the estimate itself. If costly construction decisions or sensitive political decisions are being made based on the operations estimate, it is important to know if the estimate is very precise or only a ballpark estimate.

Precision of the estimate is measured by the sampling error, which is usually expressed as a percent of the operations estimate. For example, an estimate of 10,000 annual operations with a sampling error of plus or minus 10 percent at a 95 percent confidence level means that the user can be 95 percent confident that the true number of operations lies between 9,000 (-10%) and 11,000 (+10%). The usefulness of this estimate is much greater than an estimate of 10,000 operations with a sampling error of plus or minus 50 percent. In this case the true number of operations could lie between 5,000 and 15,000 operations.

Finally, because statistical sampling provides a measure of precision, it allows sample size and cost to be adjusted to the level of precision required for a particular airport or purpose. Generally, a more precise estimate requires a larger and more costly sample. A fairly precise operations estimate, and the funding necessary to achieve it, would be required for a decision to construct a full parallel taxiway costing $400,000. Conversely, a less precise, and less expensive, estimate would be adequate for a decision to add holding aprons at the ends of a runway for $15,000. Optimal sampling based on the required degree of precision allows more airports to be sampled, or one airport to be sampled more often, for a given number of dollars.

Annual Operations Estimates

Statistical sampling procedures presented in this handbook are primarily for estimating total annual operations. That is the statistic most commonly required and consistently compared among airports. Many other statistics, including number of operations that occur in various time periods, number of operations by aircraft type, number of local and itinerant operations, daily or hourly peaks, and other valuable information may also be estimated if the sample is correctly drawn. These statistics will be discussed after basic procedures for annual operations and precision estimates are presented.

The following chapters of the handbook explain the major steps in conducting a sample of aircraft operations and estimating total operations from the sample data:

1. Pre-Sample Planning,
2. Developing a Sampling Plan,
3. Collecting Sample Data,
4. Organizing Sample Data and Estimating Operations,
5. Estimating Distribution of Operations.

Each chapter includes an explanation of the process and an example to illustrate how the procedures are to be applied. Chapter 4 includes forms for tabulating data and estimating annual operations. The final chapter, Chapter 6, Methods of Collecting Sample Data, discusses and compares alternative methods of collecting data. Appendix A, Corrections for Loss of Sample Data, discusses common problems that occur in the sampling and estimating process and how to correct them. Appendix B, Statistical Derivation of Estimating Procedures, contains statistical equations for estimating operations and the precision of the estimate.

An Example: Tri-City State Airport

The entire sampling and estimating process becomes more clear when related to an actual example where it was applied. The Tri-City State Airport near Myrtle Creek, Oregon is used as an example throughout the handbook. A brief description of the sampling process and results of the sample for Tri-City State Airport are presented here as an overview of the entire sampling procedure. Each step is discussed in more detail in the following chapters.

Tri-City State Airport has no fixed base operator and is unattended most of the time. Prior to sample counts conducted in 1983 and 1984, the State Aeronautics

Division, which owns the airport, could not be sure if there were 500 or 15,000 operations per year at the airport. An estimate of 4,500 operations per year was being used for planning purposes.

During pre-sample planning it was determined that use of an acoustical aircraft activity counter was the most practical means to obtain a sample of operations. The sampling method was chosen based on the type of information desired. In addition to total annual operations it was also desireable to estimate seasonal operations and determine whether or not multi-engine aircraft were using the airport. It also would have been useful to know the local/itinerant split and the number of helicopter operations, but these could not be identified by the acoustical counter or any other known mechanical counting method.

A sampling plan was developed for the airport that would provide an estimate of annual operations with a desired level of precision. Weekly counts of operations were made in four seasons with two counts in each season. This allowed estimates of known precision for each season as well as for the year.

During each week sampled a Rens Aircraft Activity Counter was placed at the airport. The counter recorded the sounds of all departures during the week. Aircraft departures were tallied and daily departures were doubled to arrive at operations. Departures were also classified as single engine, multi-engine, or jet aircraft.

When the sample was completed, estimates of operations were made according to the procedures described in subsequent chapters of this handbook. Total annual fixed-wing operations were estimated to be 2,274, with a 29 percent sampling error. This sampling error means that the State Aeronautics Division can now be 95 percent confident that total fixed-wing operations at Tri-City State Airport in the 1983-84 period were between 1,624 (2,274 minus 29 percent) and 2,924 (2,274 plus 29 percent). Eighteen percent of these operations were estimated to be multi-engine aircraft. In addition, there were helicopters operating at the airport, but the number of these operations could not be determined from information collected by the acoustical counter. There were no jet operations recorded by the counter.

Tri-City State Airport was one of 17 Oregon airports counted during 1983-84. Average cost for each airport counted was about $1.200. (See Chapter 6 for a discussion of other sampling methods and their costs.)

1. PRE-SAMPLE PLANNING

A number of pre-sample planning decisions must be made before the sampling plan can be developed. Figure 1 summarizes the pre-sample decisions and how they relate to the subsequent steps in the sampling process.

Determine Information Needed

The most basic decision that must be made is determining what information is needed. In most cases, total annual operations will be the primary information required, but it may also be desirable to determine operations for shorter periods or peak operations for a given period. The sampling plan will differ based on whether an annual estimate, quarterly and annual estimates, or monthly, quarterly and annual estimates are desired. The more time periods for which an estimate is desired, the more constraints there will be on the sampling plan and the larger the sample size required.

Another decision that must be made during pre-sample planning is whether any information in addition to the count of operations needs to be collected at the time of the sample. If information about each operation is desired, such as hour of operation, type of operation (local, itinerant, commuter, etc.), or type of aircraft, then plans to obtain the information must be made. Once the sample has begun, it may be too late or too costly to modify the sample in order to obtain information not anticipated at the outset. If a subsample of operations is used as a lower-cost alternative for collecting information about some of the operations counted (see Chapter 5), it must also be planned prior to beginning the sample.

Choose Sample Method

The type of operations information needed will dictate the method used to collect the sample data. Some methods, such as pneumatic tubes, only register that an operation took place. Other methods, such as visual observation, can provide information about time and type of operation and type of aircraft. A comparison of different methods of collecting sample data and their capacity to gather information about operations is included in Chapter 6.

Determine Precision

In addition to determining what is to be estimated, the desired precision of the estimate must also be determined. The desired precision will determine the size of the sample necessary to achieve the level of precision. The desired precision should also be discussed in the pre-sample stage to ensure the resulting operations estimate will be adequate for the purpose for which the estimate will be used. The more crucial or costly the decision, the more precise the estimate should be.

Determine Cost and Funding

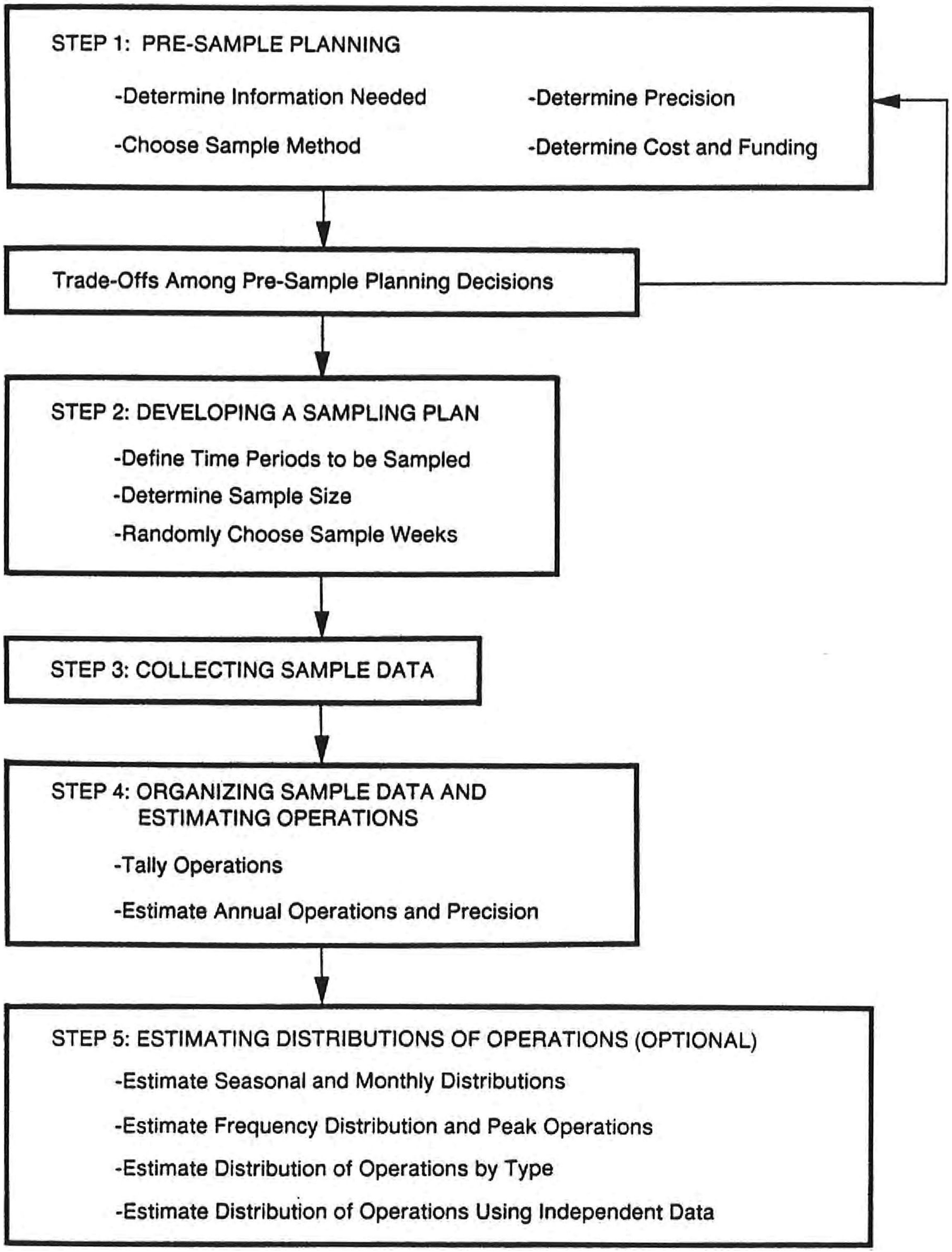
Information requirements, data collection methods, and precision all affect sampling costs. Total sampling costs must be identified during pre-sample planning to determine the funding required to implement the sampling plan. If adequate funding is not available, then a decision to modify or discontinue the sample is needed.

Trade-Offs

Once these initial decisions have been made, trade-offs between some or all of these decisions may be necessary. For example, limited funding may constrain the precision of the estimate. Generally, the lower the funding, the less precise is the estimate. Funding may also constrain the sample method used, because some methods are much more costly than others. Funding may also constrain the amount of information about operations that can be obtained and the number of periods for which operations can be estimated. Information requirements may also require trade-offs. For instance, it may be more important to know something about the type of operations, than to have a more precise estimate of total annual operations.

It is important that the pre-sample decisions be made and any necessary trade-offs reconciled before the sample plan is developed. Careful pre-sample planning will help avoid time delays and costly mistakes during the development and implementation of the sampling plan.

Figure 1. Summary of Operations Sampling and Estimating Process



2. DEVELOPING A SAMPLING PLAN

The two main objectives of a sampling plan for aircraft operations are to ensure representative time periods are sampled and a sufficient number of periods are sampled to provide an operations estimate with the required degree of precision. This section describes a sampling plan that meets these objectives and can be applied in a variety of situations.

Define Time Periods to be Sampled

Aircraft operations are known to vary according to the weather and the day of the week.[3] Operations increase during good weather (visual flight rules conditions) and decrease during bad weather (instrument flight rules conditions). Operations generally increase on the weekends if operations are predominately due to recreational or pleasure flying. On the other hand, operations will be greater on weekdays if they are largely due to business flying or air taxi services.

To capture the daily variation in operations due to type of flying, the sample must be drawn on different days of the week. The easiest and least costly way to accomplish this is to sample a cluster of seven consecutive days; that is, sample an entire week. All operations on each of the seven days sampled are counted.

In order to capture the variation in operations due to the weather, at least one week must be sampled in each season throughout the year. This is done by stratifying (i.e., dividing) the year into two or more seasons based on weather patterns. The seasons do not need to be of equal length. For much of the nation calendar quarters serve very well as seasonal divisions. At least two weeks must be sampled per season if operations estimates are to be made for each season as well as for the year.

Determine Sample Size

The size of the sample, in this case, the total number of weeks sampled, will depend on a trade-off between cost and the desired precision of the estimate. Generally, larger samples are more precise, but also more costly. Before going into detail, there are three rules of thumb for determining sample size:

1. The greater the precision desired in the estimate, the larger the sample size needed;
2. The lower the activity at an airport, the greater the variation in operations among days of the week and seasons; and
3. The greater the variation in operations among days of the week and seasons, the larger the sample size needed to make an estimate with a given degree of precision.

These three considerations are incorporated in Table 1. The table can be used to determine sample size based on the desired precision of the operations estimate and a preliminary estimate of total operations. Once the required sample size is determined, costs of collecting the sample can be estimated. If adequate funding is not available, the size and accuracy of the sample will have to be reduced.

Table 1 provides an approximation of the sample size needed when little is known about the airport to be sampled, except a preliminary estimate of total activity. A preliminary estimate of activity can be made based on the airport master plan, FAA Airport Master Records (5010-1 forms), or the estimates of the fixed base operator or manager of the airport. The table allows a more efficient use of funds by tailoring the sample size to the estimated activity level of the airport and the likely variation in operations. The table helps avoid expensive oversampling, whereby more data is collected than needed for a satisfactory estimate. It also helps avoid undersampling, resulting in an estimate with a larger sampling error than is acceptable.

If seasonal as well as annual operations estimates are required, a sample larger than needed to achieve the desired precision may be necessary. For example, if an airport with about 30,000 operations is to be sampled and a 20 percent sampling error is desired, Table 1 indicates a sample size of six weeks is adequate. However, if estimates of operations in each of four seasons are required in addition to the annual estimate, at least two weeks must be sampled in each season. Therefore, a sample size of eight weeks is needed. In this case the larger sample size was needed for the seasonal estimate requirement rather than for the precision requirement.

Once the total sample size is determined, it must be divided among seasons. A good rule to follow is to allocate the total sample size among seasons based on the relative size of each season. For example, if there are two seasons, one three months long (one-fourth of the year) and the other nine months long (three-fourths of the year), then one-fourth of the total sample size would be drawn from the first season and three-fourths of the sample would be drawn from the second season. If the seasons are of equal length, then the total sample size would be divided equally among the seasons. These are called seasonally proportional samples.

In some cases the sample may not be seasonally proportional. Sample weeks divided proportionally among seasons may result in only one week being sampled in a season. However, if a seasonal estimate is desired, at least two weeks must be sampled. The added week will result in

[3]Variation in aircraft operations by weather and day of the week has been observed during aircraft operations counts in Florida, Idaho, Michigan, Oregon, Texas, and Washington.

Table 1. Approximate Percent Sampling Error in Annual Operations Estimate at 95 Percent Confidence Level by Size of Airport and Size of Sample

Approximate Annual Operations at Airport Being Sampled	Number of Weeks Sampled Per Year								
	4	5	6	7	8	9	10	11	12
Less Than 900	± 54%	± 48%	± 44%	± 40%	± 37%	± 34%	± 32%	± 30%	± 29%
900 - 2,399	51	45	41	37	34	32	30	28	27
2,400 - 4,399	47	42	38	35	32	30	28	26	25
4,400 - 7,199	44	39	35	32	30	27	26	24	23
7,200 - 10,499	40	35	32	29	27	25	24	22	21
10,500 - 14,599	36	32	29	27	25	23	21	20	19
14,600 - 19,199	33	29	26	24	22	21	19	18	17
19,200 - 24,599	29	26	23	21	20	18	17	16	15
24,600 - 30,499	25	23	20	19	17	16	15	14	13
30,500 And Over	22	19	17	16	15	14	13	12	12

a larger sample in that season. A non-proportional sample also results if a season is intentionally sampled more heavily to obtain a more precise estimate of operations for that particular season.

Randomly Choose Sample Weeks

Assuming the sample is seasonally proportional, weeks can be sampled at equal intervals throughout the year. One week must be randomly chosen and the others selected at equal intervals around the randomly chosen week.

If the sample is not proportional, then it will be necessary to select sample weeks independently for each season. In this case one week in each season is randomly chosen and additional weeks chosen are spaced equally throughout each season.

Table 2, "Random Numbers from 1 to 52", may be used to select a week at random. First, number all weeks in the year or the season. For example, to randomly choose one week out of the year, weeks are numbered from 1 to 52. Weeks can be numbered starting with the first week in January or with the first week in the first season to be sampled. To randomly choose one week out of a three-month season, weeks are numbered from 1 to 13, starting with the first week in the season.

To use Table 2, arbitrarily choose any column and any row in the table. Where they intersect is a random number between 1 and 52. This number corresponds to one of the weeks numbered above and serves to randomly choose that week for the sample. For example, if column number 9 and row number 23 are arbitrarily chosen, the number where they intersect is 35. Therefore, week number 35 is chosen for the sample. It should be noted that this week will not necessarily be the first week in which aircraft operations are counted. The first week counted will depend on when the sample is scheduled to begin.

The week randomly chosen from Table 2 serves as a starting point for choosing the additional weeks to be included in the sample. In a seasonally proportional sample all additional weeks are sampled at equal intervals throughout the year. The sampling interval is determined by dividing the total number of weeks in the year (52) by the sample size. For example, if an eight-week sample is planned, the interval will be 6.5 weeks. If week 35 is randomly chosen from Table 2, then weeks 3, 9, 16, 22, 29, 42, and 48 would also be included in the sample. If a week chosen does not fall entirely within one season, it should be assigned to the season in which four of the seven days fall. For a proportional sample, this process ensures the sample weeks are randomly chosen and are evenly spaced throughout the year.

If the sample is not seasonally proportional, then one week in each season must be randomly chosen. Additional weeks are chosen at equal intervals throughout the season. The interval is established separately for each season by dividing the number of weeks in the season by the sample size for the season.

When randomly choosing a week in a season the random number picked from Table 2 may not match any of the week numbers in the season. For example, in the January to March winter season, the weeks are numbered from 1 to 13. However, number 46 may be picked from Table 2. In such a case, move up or down the same column, or left or right along the same row until a usable number is reached, in this case a number from 1 to 13. If, in moving through the table, the edge is reached (top, bottom, left, or right) jump to the opposite edge of the table and continue moving in the same direction until a usable number is reached.

In some cases a number of airports will be counted during the same period. If one individual or mechanical counter is used, no two airports can be sampled simultaneously. Therefore, it is necessary to schedule sample weeks that do not overlap. This is done by choosing sample weeks for the first airport as discussed above. Once chosen, these weeks are no longer available to be sampled. Sample weeks for the second airport are chosen in the same manner from the remaining weeks. This is called sampling without replacement. The sampling process is repeated with fewer weeks available for each successive airport.

After the sampling plan has been developed it should be reviewed to ensure it can be implemented as intended. This is particularly important when sample weeks have been chosen for several airports without replacement. The sample plan should be checked to ensure:

1. The number of weeks sampled are sufficient for the desired precision and for the periods being estimated;
2. The required number of weeks are sampled in each season; and
3. Each sampled week falls entirely within one season, or if not, is assigned to the season in which four of the seven days fall.

Example

The above sampling plan was applied to Tri-City State Airport in 1983-84. The year was divided into four seasons--winter, spring, summer, and fall--which correspond to the four calendar quarters. An estimate of annual operations and seasonal operations was required.

Table 1 was used to determine the sample size for Tri-City State Airport. Little was known about the level of activity at the airport, but for planning purposes it was assumed to be about 4,500 operations. A sampling error of 30 percent was considered tolerable for the estimate of annual operations. Given this information, Table 1 indicates a sample size of eight weeks would provide a sampling error of 30 percent and would therefore be adequate for the airport. The eight-week sample was equally divided among the four seasons, resulting in a seasonally proportional sample with two weeks sampled per season. At least two weeks per season are necessary to make seasonal operations estimates of a known precision.

Table 2. Random Numbers From 1 to 52

ROW \ COLUMN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	3	11	44	21	37	37	50	24	52	46	19	6	27	5	49	44	30	50	30	41	29	10	6	5	32
2	49	6	9	51	26	6	7	44	2	26	47	46	11	18	9	49	14	1	39	24	2	50	33	10	20
3	40	8	51	36	15	25	20	50	26	14	4	3	39	3	32	11	39	37	25	23	21	25	12	5	29
4	31	26	38	43	25	21	11	34	6	40	39	30	39	14	48	9	35	29	19	10	44	25	10	44	29
5	33	45	29	28	13	34	41	49	30	2	49	30	50	27	28	30	32	26	24	12	15	39	48	46	50
6	48	46	48	36	37	9	26	33	17	15	44	28	29	30	25	38	5	45	30	35	43	45	45	20	24
7	24	32	28	39	39	40	48	32	23	6	34	51	8	2	45	2	13	17	41	43	49	15	9	24	13
8	24	26	49	10	32	51	28	16	51	13	33	37	31	9	35	31	27	44	28	24	51	46	28	9	11
9	41	44	4	40	10	5	45	29	27	7	9	43	30	51	40	41	39	25	2	50	29	36	9	38	50
10	13	41	30	18	43	49	8	23	19	9	41	11	14	34	32	47	50	31	49	18	25	44	45	30	36
11	2	46	6	36	8	35	38	23	4	22	52	14	30	9	43	27	35	25	42	34	32	39	2	23	23
12	39	32	1	30	22	16	8	9	39	49	2	33	32	3	40	12	24	40	27	11	33	5	41	6	22
13	36	18	48	23	15	45	37	19	45	51	8	52	35	52	3	14	16	22	44	13	47	14	21	3	35
14	35	4	18	27	6	5	29	33	39	45	27	15	2	31	18	37	11	46	31	27	43	18	31	29	2
15	8	32	25	18	43	46	44	11	28	21	28	36	21	11	30	35	45	14	38	51	21	30	43	40	13
16	26	44	30	47	12	11	16	51	7	51	42	46	5	32	49	8	18	36	11	49	2	30	15	24	14
17	22	12	30	19	5	13	40	23	39	30	36	2	45	8	50	31	45	41	3	7	19	7	27	3	34
18	32	39	6	44	8	16	26	18	32	33	18	23	26	9	25	25	26	41	13	16	40	44	10	31	45
19	48	42	31	15	20	41	12	17	49	45	34	10	9	17	28	18	14	29	50	43	13	5	19	23	21
20	26	20	41	22	23	42	47	14	21	51	22	34	11	16	5	42	7	25	37	50	25	12	2	15	21
21	47	44	49	4	47	43	45	42	4	12	37	15	15	13	48	24	17	44	17	16	49	3	38	5	44
22	20	39	4	37	35	31	35	31	32	18	33	36	25	33	28	28	22	41	51	47	27	48	49	25	15
23	27	25	17	36	13	14	23	15	35	30	25	30	15	26	25	26	33	19	25	31	15	22	51	7	46
24	14	36	39	18	13	26	43	25	26	38	47	50	33	6	42	2	45	4	26	26	22	10	15	7	11
25	6	38	28	32	42	23	18	8	40	20	22	3	28	47	32	26	30	50	37	27	38	41	12	10	11
26	28	28	19	21	7	15	26	29	45	12	30	27	45	34	2	21	11	28	23	46	20	21	52	21	26
27	18	29	21	21	40	6	36	9	44	30	50	28	33	48	49	15	16	12	37	15	20	38	51	18	9
28	46	47	24	26	46	46	26	45	44	16	10	20	33	26	12	50	39	44	22	46	30	25	36	43	40
29	8	48	15	23	3	20	49	14	10	37	33	22	44	18	25	43	38	4	41	7	36	49	30	46	9
30	3	46	47	29	9	4	45	36	21	11	34	10	11	31	40	18	6	36	13	8	41	21	15	8	20

It should be noted that Table 1 provides only an approximation of sampling error based on a preliminary estimate of airport activity and sample size. The actual sampling error calculated from the sample data may differ. For example, the eight-week sample for Tri-City State Airport resulted in an actual sampling error of 28.6 percent, rather than the 30 percent indicated by the table.

Figure 2 illustrates the sampling plan for Tri-City State Airport. The counting program started in the third quarter (summer), which was numbered season 1. The first of the eight weeks to be sampled was randomly chosen using a random numbers table. First, all weeks in the year were numbered consecutively from 1 to 52, starting with the first week in season 1 (July 1-7, 1983). Then, starting at an arbitrary place in the random numbers table, the number 5 was picked. Therefore week number five (July 29-August 4, 1983) was the first sample week chosen.

Since a proportional sample was planned, additional weeks were sampled at equal intervals throughout the year. The sampling interval was determined based on the total number of weeks in the year (52) divided by the sample size (8), which equals 6.5 weeks. Therefore, starting with week number 5, successive weeks were chosen in multiples of 6.5 (Table 3). Week numbers were then rounded to the nearest whole number. After all eight weeks were chosen, they were renumbered from 1 to 8 in the order that they will actually be counted.

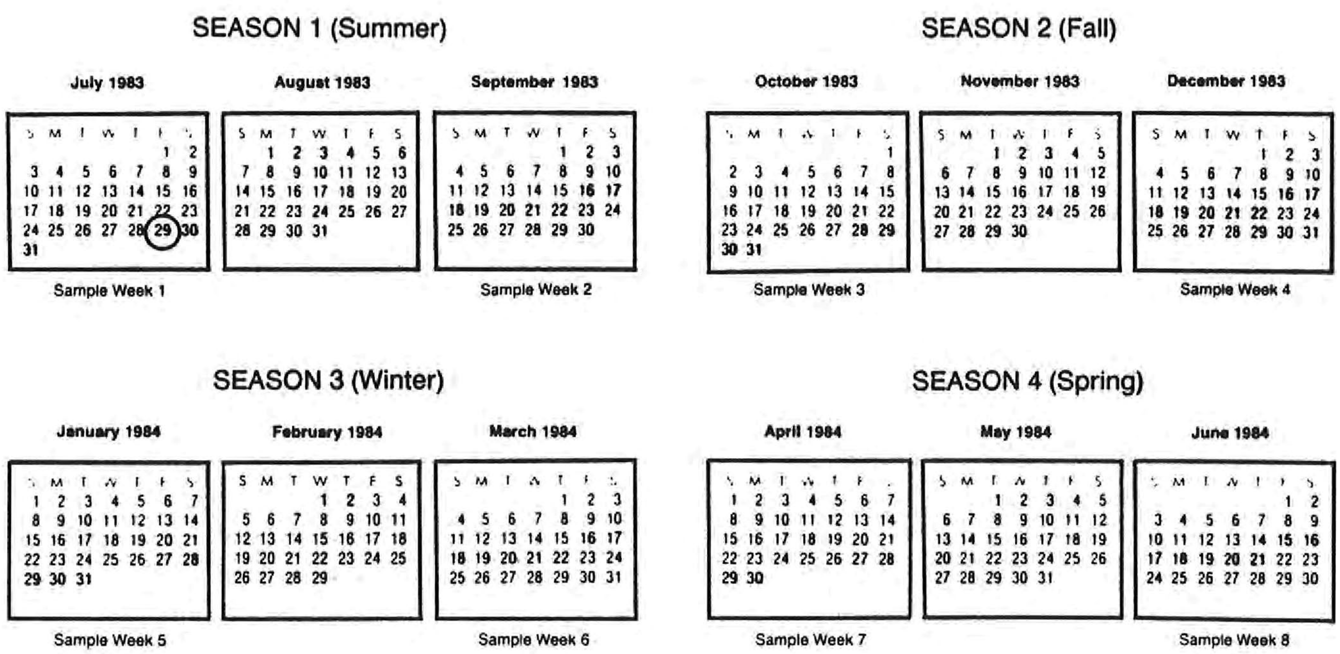
Note that the first week randomly chose from Table 2 is not necessarily the first week to be counted. If week number 20 had been randomly chosen from the table, then in choosing additional weeks it would have been necessary to "wrap around" from June in season 4 to July in season 1 to continue choosing weeks until eight weeks had been picked (Figure 2). In such a case, the eight weeks chosen would be renumbered from 1 to 8 starting in July to reflect the order in which they will actually be counted.

Figure 2. Sampling Plan for Tri-City State Airport

Seasons = 4, each 13 weeks long (correspond to calendar quarters)

Sample Size = 8 weeks, 2 weeks in each season (seasonally proportional)

Sample Interval = 6.5 weeks (52÷8=6.5)



○ First week randomly chosen

Additional weeks sampled at equal intervals

Table 3. Randomly Chosen Weeks for Tri-City State Airport

6.5 Week Intervals	Sample Week Chosen (Rounded)	Week Renumbered In Order of Count
5*	5	1
11.5	12	2
18.0	18	3
24.5	25	4
31.0	31	5
37.5	38	6
44.0	44	7
50.5	51	8

*5 chosen from Random Numbers Table

3. COLLECTING SAMPLE DATA

There are a number of different methods to collect sample operations data. Different counting methods, including their relative pros and cons, are discussed in Chapter 6.

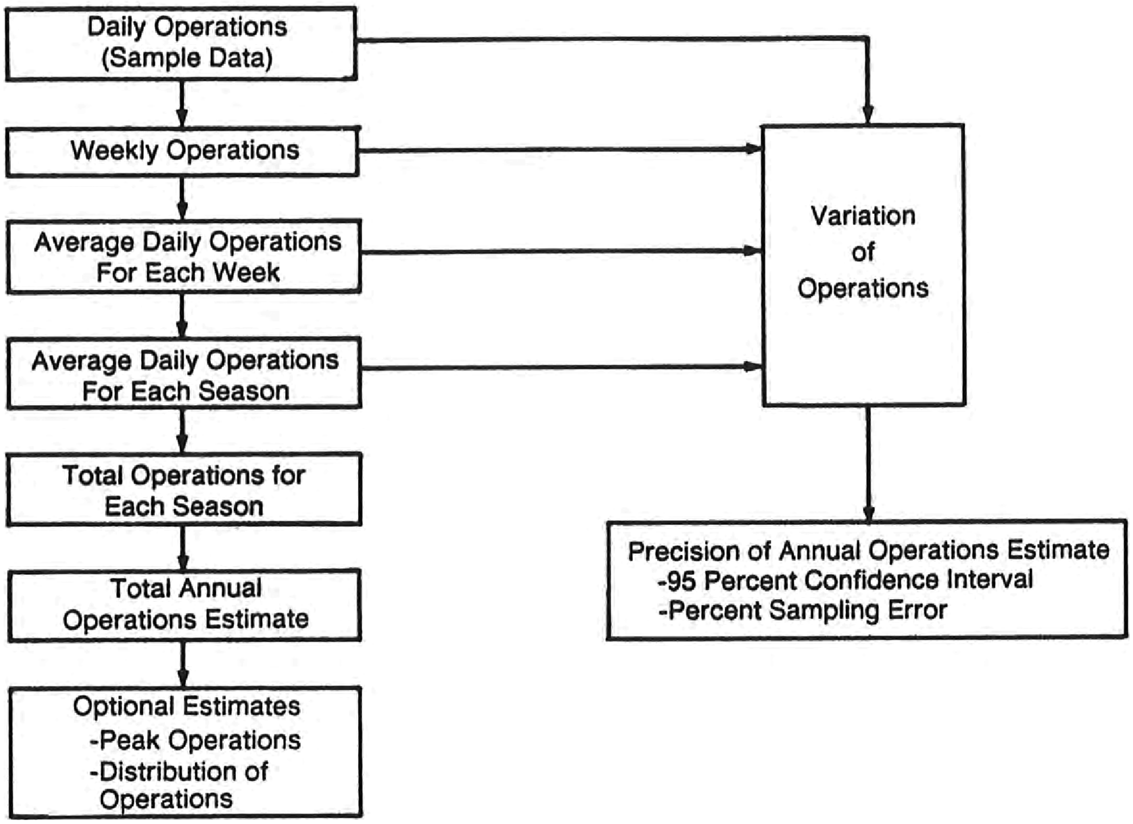
Regardless of the counting method used, there are two primary concerns in collecting sample data: that operations counts are accurate and that the schedule developed as part of the sampling plan is followed. Statistical sampling is a proven process, but it is only as reliable as the sample data collected.

To ensure accurate data, it is important that counting procedures are applied correctly and the results interpreted within the limitations of the technique used. For example, an acoustical counter normally only records departures, which must be doubled to measure operations. If the counter is incorrectly positioned it may not record all departures. Many procedures using pneumatic tubes actually record activity on taxiways. The data must then be accurately related to operations to obtain meaningful counts. Visual observation directly counts operations and is therefore less subject to errors in interpretation. However, procedures for visual counts must be established and followed to ensure that the counts are consistent and complete. If information about each operation is being gathered, such as local or itinerant flight, the characteristics must be defined and the observer trained in how to classify each operation.

In addition to the correct application of counting methods, it is extremely important that sampling plans be followed and that counts be conducted as scheduled. Any deviation from the plan may reduce accuracy by interfering with the random choice of counting periods, or by reducing the sample size. If the sample is not random, then biases that statistical samples are designed to eliminate may be reintroduced. If particular types of weather conditions, or other factors affecting aviation activity are favored in collecting the sample data, then the estimate may not accurately reflect activity at the airport.

Reducing the sample size, either by reducing the number of days counted in a week or by reducing the number of weeks counted in a season, will reduce precision as reflected by an increase in the sampling error. In some cases schedule changes or loss of data can be dealt with, as described in Appendix A. However, given the seasonal nature of general aviation activity, if at least one week is not sampled in each season, then no reliable annual operations estimate can be made. In such a case the estimate may be biased upward if a low season was missed, or may be biased downward if a busy season was missed.

Figure 3. Steps in Estimating Annual Operations and the Precision of the Annual Operations Estimate



4. ORGANIZING SAMPLE DATA AND ESTIMATING OPERATIONS

As the sample data is collected, it is important to have a systematic means to organize and tabulate the sample data and to estimate operations. Forms have been developed to guide the user step-by-step through a series of calculations that end in an estimate of annual operations and a measure of the precision of the estimate of annual operations. Figure 3 summarizes the calculations and shows their relationship to one another. Estimating equations are presented in Appendix B, Statistical Derivation of Estimating Procedures, for users who prefer to make the calculations using equations rather than the forms.

The first step is to tally weekly operations. Average daily operations for each week can then be calculated. These are combined to find average daily operations for each season. The season averages are expanded to total operations in each season. The season totals are then added to obtain an estimate of total annual operations.

Daily, weekly, and average daily operations for each week and for each season are all used to calculate the variation in operations. The variation in operations provides a way to determine the precision or range of the estimate of annual operations. Precision can be expressed as a confidence interval (e.g., plus or minus 1,000 operations) The confidence interval is an estimated range in which one can be 95 percent confident that the true number of operations will fall.[4] Precision can also be expressed as a percent sampling error, which is the confidence interval divided by estimated operations (e.g., the confidence interval of 1,000 operations divided by the annual estimate of 10,000 operations equals a sampling error of plus or minus 10 percent of the estimated annual operations).

The first section contains a set of standard forms and instructions that provide a step-by-step format for making operations estimates. The forms can be photocopied and used directly, or they can be computerized with standard spread sheet programs.

The second section contains Figures 4 through 9, which illustrate how to fill out each form, using sample data from Tri-City State Airport.

If sample data are incomplete so that forms cannot be completed as described, Appendix A, Corrections for Loss of Sample Data, describes alternate procedures for calculation of annual operations and the sampling error.

Sampling and Estimating Forms

The following forms and their instructions are presented in this section:

Form 1, Sample Data, for tabulating and summarizing the daily sample data; [5]

Form 2, Weekly Data, for tallying total weekly operations and estimating average daily operations;

Form 3, Seasonal Data, for estimating average daily operations and the variance of the estimate for each season; and

Form 4, Annual Estimates, for estimating total annual operations and the 95 percent confidence interval and sampling error of the estimate of total annual operations.

[4]The 95 percent refers to the confidence level or degree of certainty that the true number of operations will fall within the confidence interval. Calculations in this handbook are based on a 95 percent confidence level.

[5]Form 1 is one example of possible sample data forms that could be used. The format of the data form will vary according to the type of information collected about aircraft operations. The minimum requirement for Form 1 is to provide a tally of total operations for each day counted.

INSTRUCTIONS FOR FORM 1
SAMPLE DATA

The purpose of Form 1 is to serve as a worksheet to tally or tabulate the sample data and to obtain total daily operations.

In the boxes at the top of the form fill in the name of the airport sampled and the season number and week number from which the data were collected. Weeks sampled are numbered consecutively throughout the year. Fill in the date of each of the seven days sampled.

Day 1 — Tabulate the number of operations counted during each hour in Day 1. Add the hourly operations. Enter the answer in the total box at the end of the column for Day 1.

Day 2-7 — Repeat the tabulation of hourly operations for each day. Add each column of hourly operations to obtain total operations for each day. Daily operations will be transferred to Form 2, Weekly Data, column (B).

FORM 1
SAMPLE DATA

Airport Name	
Season No.	Week No.

DAY:	1	2	3	4	5	6	7
TIME OF DAY	Date	Date	Date	Date	Date	Date	Date
MID NIGHT							
01:00							
02:00							
03:00							
04:00							
05:00							
06:00							
07:00							
08:00							
09:00							
10:00							
11:00							
12:00							
13:00							
14:00							
15:00							
16:00							
17:00							
18:00							
19:00							
20:00							
21:00							
22:00							
23:00							
TOTALS							

INSTRUCTIONS FOR FORM 2
WEEKLY DATA

The purpose of Form 2 is to calculate total operations and average daily operations for each week, and other numbers that will be used on Form 3.

In the boxes at the top of Form 2 fill in the name of the airport sampled and the season number and week number from which the data were collected.

Column (A)	Fill in the date of each day sampled on the lines in column (A).
Column (B)	Fill in the number of operations counted on each date on the lines in column (B). Operations for each date are obtained from the bottom row of Form 1.
Box (C)	Add the values in column (B). Enter the answer, total weekly operations, in box (C).
Box (D)	Divide the value in box (C) by the number of days counted in the week (normally 7). Enter the answer, average daily operations, in box (D). This number will be used in column (E) and transferred to Form 3, column (A).
Column (E)	Subtract the value in box (D) from the value on line 1 in column (B). Enter the answer on line 1 of column (E). Repeat this step, subtracting (D) from each value in column (B).
Column (F)	Square each value in column (E) and enter the answers in column (F). (All squared numbers will be positive.)
Box (G)	Add the values in column (F). Enter the answer in box (G). This number will be transferred to Form 3, column (K).

FORM 2
WEEKLY DATA

Airport Name	
Season No.	Week No.

	(A)	(B)	(E)	(F)
DAY	DATE	DAILY OPERATIONS	COLUMN (B)-(D)	COLUMN (E) SQUARED
1				
2				
3				
4				
5				
6				
7				

TOTAL WEEKLY OPERATIONS — (C) Sum of Col. (B)

(G) Sum of Col. (F) — Transfer (G) to Form 3. Col. (K)

AVERAGE DAILY OPERATIONS — (D) (C)÷No. of Days — Use in Col. (E)

Transfer (D) to Form 3. Col. (A)

Complete a separate Weekly Data Form for each week sampled in each season. For example, if three weeks are sampled per season and the year is divided into four seasons, then a total of 12 Weekly Data Forms are completed.

INSTRUCTIONS FOR FORM 3
SEASONAL DATA

The purpose of Form 3 is to find average daily operations for each season and to calculate numbers that will be used on Form 4. If data is not stratified into seasons it will still be necessary to complete this form, treating all data as though they were from a single year-long season.

In the boxes at the top of Form 3 fill in the name of the airport sampled. Fill in the number of the season from which the sample data were collected. Also fill in the season size, N (total number of weeks in the season), the sample size, n (number of weeks sampled in the season), and the week size, M (normally 7).

(Note: Form 3 assumes a cluster of 7 days (one week) is sampled, and therefore N, n, and M are based on weeks (see Figure 8). If a cluster of days less than one week or greater than one week is sampled, then N will be the total number of clusters in the season; n will be the number of clusters sampled in the season, and M will be the number of days in the cluster. For example, if two 2-week clusters are sampled in a three-month season, then N is 6.5, n is 2, and M is 14.)

Column (A)	Fill in the average daily operations per week on the lines in column (A). Average daily operations per week are transferred from Form 2, box (D). Column (A) may have 2 or more lines depending on the number of weeks sampled.
Box (B)	Add the values in column (A) and enter the answer in box (B).
Box (C)	Divide the value in box (B) by n (find n in box at top of Form 3). Enter the answer in box (C). This number will be used in column (D) and transferred to Form 4, column (H).
Column (D)	Subtract the value in box (C) from the value on line 1 in column (A). Enter the answer on line 1 in column (D). Repeat this step for each value in column (A).
Column (E)	Square each value in column (D) and enter the answer (always a positive number) in column (E).
Box (F)	Add the values in column (E) and enter the answer in box (F).
Box (G)	Subtract 1 from n (find n in box at top of Form 3) and enter the answer in box (G).
Box (H)	Divide the value in box (F) by the value in box (G) and enter the answer in box (H).
Box (I)	Subtract 1 from N (find N in box at top of Form 3) and enter the answer in box (I).
Box (J)	Multiply the value in box (H) by the value in box (I). Enter the answer in box (J).
Column (K)	Enter the value from Form 2, box (G) for each week on the appropriate line in column (K).
Box (L)	Add the values in column (K) and enter the answer in box (L).
Box (P)	Subtract 1 from M (find M in box at top of Form 3). Multiply the value (M-1) by n and enter the answer in box (P).
Box (Q)	Divide the value in box (L) by the value in box (P) and enter the answer in box (Q).
Box (R)	Subtract 1 from M. Multiply the value (M-1) by N and enter the answer in box (R).
Box (S)	Multiply the value in box (Q) by the value in box (R) and enter the answer in box (S).
Box (T)	Add the values in box (J) and box (S) and enter the answer in box (T).
Box (U)	Multiply N times M and then subtract 1. Enter the answer in box (U).
Box (V)	Divide the value in box (T) by the value in box (U) and enter the answer in box (V). This value is also transferred to Form 4, column (K).

FORM 3
SEASONAL DATA

Airport Name

Season No.

TOTAL WEEKS IN SEASON: N

WEEKS SAMPLED IN SEASON: n

DAYS IN WEEK: M

WEEK	(A) AVERAGE DAILY OPERATIONS (FORM 2,(D))	(D) COLUMN (A)-(C)	(E) COLUMN (D) SQUARED	(K) FROM FORM 2, (G)
1				
2				
3				
4				

(B) Sum Col. (A)

(F) Sum Col. (E)

(L) Sum Col. (K)

(G) n-1

(P) n x (M-1)

AVERAGE DAILY OPERATIONS FOR SEASON (C) (B)÷n — Use to Calculate Col. (D); Transfer to Form 4, Col. (H)

(H) (F)÷(G)

(Q) (L)÷(P)

(I) (N-1)

(R) N x (M-1)

(J) (H) x (I)

(S) (Q) x (R)

(T) (J) + (S)

(U) (NxM) - 1

(V) T÷(U) — Transfer to Form 4, Col. (K)

Complete a separate Seasonal Data Form for each season. For example, if the year is divided into four seasons, then a total of four Seasonal Data Forms are completed. More rows may be added to Form 3 if more than four weeks are sampled in the season.

INSTRUCTIONS FOR FORM 4
ANNUAL ESTIMATES

The purpose of Form 4 is to expand the sample data to estimate total annual operations and to calculate measures of precision of the estimate of annual operations, including the confidence interval and the percent sampling error.

In the boxes at the top of Form 4 fill in the name of the airport sampled and the period of the sample.

Column (A) Fill in the total number of days, D, in each season on the lines in column (A). Use the actual number of calendar days, not number of weeks, N, times 7 days. (If data is not stratified by season, only one line will be used.)

Column (B) Square each value of D and enter the answer in column (B).

Column (C) Fill in the number of days sampled, d, in each season on the lines in column (C).

Column (D) For each season divide D^2 in column (B) by d in column (C) and enter the answer in column (D).

Column (E) For each season divide d in column (C) by D in column (A) and enter the answer in column (E).

Column (F) Subtract $\frac{d}{D}$ in column (E) from 1 and enter the answer in column (F).

Column (G) Transfer the value of D for each season from column (A) to the appropriate line in column (G).

Column (H) Fill in the average daily operations for each season on the lines in column (H). Average daily operations are obtained from Form 3, box (C).

Column (I) For each season, multiply D in column (G) by average daily operations in column (H). Enter the answer on the appropriate line in column (I).

Box (J) Add the values in column (I) and enter the answer, annual operations, in box (J).

Column (K) Fill in the value from Form 3, box (V) for each season on the appropriate line in column (K).

Column (L) For each season, transfer the values for $\frac{D^2}{d}$ from column (D) to column (L).

Column (M) For each season multiply the value in column (K) by $\frac{D^2}{d}$ in column (L). Enter the answer in column (M).

Column (N) For each season transfer the value $1 - \frac{d}{D}$ from column (F) to column (N).

Column (O) For each season multiply the value in column (M) by $1 - \frac{d}{D}$ in column (N) and enter the answer in column (O). This value is the variance of operations in each season.

Box (P) Add the values in column (O). Enter the answer, the variance of estimated annual operations, in box (P).

Box (Q) Take the square root of the value in box (P) and enter the answer in box (Q).

Box (R) Find the appropriate t-value from the chart, based on the value (d-1). (Find d from column (C), then subtract 1.) Use the lowest value of d in column (C). Enter the t-value in box (R).

Box (S) Multiply the value in box (Q) by the t-value in box (R). Enter the answer in box (S). This is the 95 percent confidence interval or range of the estimated operations. It is a measure of the precision of the annual operations estimate.

Box (T) Divide the value in box (S) by the value in box (J) and multiply by 100. Enter the answer in box (T). This is the percent sampling error, which is also a measure of the precision of the annual operations estimate.

FORM 4
ANNUAL ESTIMATES

Airport Name	
Sample Period	
From:	To:

	(A)	(B)	(C)	(D)	(E)	(F)
SEASON	TOTAL DAYS D	D^2	SAMPLED DAYS d	$\frac{D^2}{d}$	$\frac{d}{D}$	$1 - \frac{d}{D}$
1						
2						
3						
4						

	(G)	(H)	(I)
SEASON	TOTAL DAYS D	AVERAGE (FORM 3, (C))	TOTAL (G) x (H)
1			
2			
3			
4			
		ANNUAL OPERATIONS	(J) Sum of Col. (I)

	(K)	(L)	(M)	(N)	(O)
SEASON	FROM FORM 3, (V)	$\frac{D^2}{d}$	COLUMN (K) x COLUMN (L)	$1 - \frac{d}{D}$	COLUMN (M) x COLUMN (N)
1					
2					
3					
4					
				VARIANCE OF OPERATIONS	(P) Sum of Col. (O)

t-VALUE CHART
Find Lowest Value of d from Column (C)

If d-1.	then	t
3		3.182
4		2.776
5		2.571
6		2.447
7		2.365
8		2.306
9		2.262
10		2.228
11		2.201
12		2.179
13		2.160
14		2.145
15		2.131
16		2.120
17		2.110
18		2.101
19		2.093
20		2.086
30		2.042
40		2.021
50		2.009
60		2.000
80		1.990

	(Q) $\sqrt{(P)}$
t-VALUE FROM CHART	(R)
95% CONFIDENCE INTERVAL	(S) ± (Q) x (R)
PERCENT SAMPLING ERROR	(T) ± ((S)÷(J)) x 100

Examples of How To Fill Out Forms 1 through 4

The following figures illustrate how Forms 1 through 4 are filled out, using sample operations data from Tri-City State Airport (see Figure 2 for a review of the Tri-City State Airport sampling plan). Figures 4 and 5 each show how Form 1, Sample Data, is filled out for one week of operations data. Two figures are shown because at least two weeks of data are needed to illustrate how Forms 3 and 4 are filled out. A total of eight Sample Data Forms, one for each of the eight weeks sampled, are needed for Tri-City State Airport.

Figures 6 and 7 each show how Form 2, Weekly Data, is filled out. Two figures are shown because a separate Form 2 is needed for each Form 1 used. The boxes at the top of each of the eight Form 2's used for Tri-City State Airport are filled out the same as the eight Form 1's.

Figure 8 shows how Form 3, Seasonal Data, is calculated. A separate Form 3 is completed for each season. The Tri-City State Airport sampling plan requires four Seasonal Data Forms, one of which is shown in Figure 8. Calculations from Figure 8 and from the other three Seasonal Data Forms (not shown) are transferred to Form 4 (Figure 9).

Figure 9 shows how the numbers and calculations from each of the four seasons are combined on Form 4 to estimate annual operations and the precision of the estimate.

Figure 4. Example of Form 1, Sample Data For Week Number 1

FORM 1
SAMPLE DATA

Airport Name	Tri-City State
Season No 1	Week No 1

DAY:	1	2	3	4	5	6	7
TIME OF DAY	Date 7/29/83	Date 7/30/83	Date 7/31/83	Date 8/1/83	Date 8/2/83	Date 8/3/83	Date 8/4/83
MID NIGHT							
01:00							
02:00							
03:00							
04:00							
05:00							
06:00							
07:00							2
08:00							4
09:00							
10:00	2			2	4		
11:00			2		2		
12:00	6		2	2	2	2	2
13:00	2				2	2	
14:00	10		2	2			2
15:00	2		2				2
16:00	6	4					
17:00		2					2
18:00							
19:00							
20:00							
21:00							
22:00							
23:00							
TOTALS	28	6	8	6	10	4	14

Figure 5. Example of Form 1, Sample Data For Week Number 2

FORM 1
SAMPLE DATA

Airport Name	Tri - City State
Season No 1	Week No 2

DAY:	1	2	3	4	5	6	7
TIME OF DAY	Date 9/16/83	Date 9/17/83	Date 9/18/83	Date 9/19/83	Date 9/20/83	Date 9/21/83	Date 9/22/83
MID NIGHT							
01:00							
02:00							
03:00							
04:00							
05:00							
06:00							
07:00							
08:00							
09:00				2			
10:00			2				
11:00							
12:00	4			10			
13:00	2	2					6
14:00							
15:00						4	
16:00							
17:00						2	
18:00							
19:00	2						
20:00							
21:00							
22:00							
23:00							
TOTALS	8	2	2	12	0	6	6

Figure 6. Example of Form 2, Weekly Data
For Week Number 1

FORM 2
WEEKLY DATA

Airport Name: TRI-CITY STATE
Season No.: 1 | Week No: 1

	(A)	(B)	(E)	(F)
DAY	DATE	DAILY OPERATIONS	COLUMN (B)-(D)	COLUMN (E) SQUARED
1	7/29/83	28	17.14	293.78
2	7/30/83	6	-4.86	23.62
3	7/31/83	8	-2.86	8.18
4	8/1/83	6	-4.86	23.62
5	8/2/83	10	-.86	.74
6	8/3/83	4	-6.86	47.06
7	8/4/83	14	3.14	9.86
	TOTAL WEEKLY OPERATIONS	(C) 76 (Sum of Col. (B))		(G) 406.86 (Sum of Col. (F))
	AVERAGE DAILY OPERATIONS	(D) 10.86 ((C) ÷ No. of Days)		

Use in Col. (E)

Transfer (G) to Form 3, Col. (K)

Transfer (D) to Form 3, Col. (A)

Complete a separate Weekly Data Form for each week sampled in each season. For example, if three weeks are sampled per season and the year is divided into four seasons, then a total of 12 Weekly Data Forms are completed.

Figure 7. Example of Form 2, Weekly Data For Week Number 2

FORM 2
WEEKLY DATA

Airport Name	TRI - CITY STATE
Season No. 1	Week No 2

DAY	(A) DATE	(B) DAILY OPERATIONS	(E) COLUMN (B)-(D)	(F) COLUMN (E) SQUARED
1	9/16/83	8	-2.86	8.18
2	9/17/83	2	- 3.14	9.86
3	9/18/83	2	- 3.14	9.86
4	9/19/83	12	6.86	47.06
5	9/20/83	0	-5.14	26.42
6	9/21/83	6	.86	.74
7	9/22/83	6	.86	.74
	TOTAL WEEKLY OPERATIONS	(C) 36 (Sum of Col. (B))		(G) 102.86 (Sum of Col. (F))

AVERAGE DAILY OPERATIONS: (D) 5.14 ((C) ÷ No. of Days)

Use in Col (E)

Transfer (D) to Form 3, Col. (A)

Transfer (G) to Form 3, Col (K)

Complete a separate Weekly Data Form for each week sampled in each season. For example, if three weeks are sampled per season and the year is divided into four seasons, then a total of 12 Weekly Data Forms are completed.

Figure 8. Example of Form 3, Seasonal Data For Season Number 1

FORM 3
SEASONAL DATA

Airport Name: Tri-City State
Season No.: 1

TOTAL WEEKS IN SEASON	N	13
WEEKS SAMPLED IN SEASON	n	2
DAYS IN WEEK	M	7

WEEK	(A) AVERAGE DAILY OPERATIONS (FORM 2,(D))	(D) COLUMN (A)-(C)	(E) COLUMN (D) SQUARED	(K) FROM FORM 2, (G)
1	10.86	2.86	8.18	406.86
2	5.14	-2.86	8.18	102.86
3				
4				

(B) 16.00 — Sum Col. (A)

AVERAGE DAILY OPERATIONS FOR SEASON (C) 8.00 — (B)÷n

Use to Calculate Col. (D)

Transfer to Form 4, Col. (H)

(F) 16.36 — Sum Col. (E)	(L) 509.72 — Sum Col. (K)
(G) 1 — n-1	(P) 12 — n x (M-1)
(H) 16.36 — (F)÷(G)	(Q) 42.48 — (L)÷(P)
(I) 12 — (N-1)	(R) 78 — N x (M-1)
(J) 196.32 — (H) x (I)	(S) 3313.44 — (Q) x (R)

(T) 3509.76 — (J) + (S)

(U) 90 — (NxM) - 1

(V) 39.00 — T÷(U)

Transfer to Form 4, Col. (K)

Complete a separate Seasonal Data Form for each season. For example, if the year is divided into four seasons, then a total of four Seasonal Data Forms are completed. More rows may be added to Form 3 if more than four weeks are sampled in the season.

Figure 9. Example of Form 4, Annual Estimates

FORM 4
ANNUAL ESTIMATES

Airport Name: TRI - CITY STATE
Sample Period From: 7/83 To: 6/84

SEASON	(A) TOTAL DAYS D	(B) D^2	(C) SAMPLED DAYS d	(D) $\frac{D^2}{d}$	(E) $\frac{d}{D}$	(F) $1 - \frac{d}{D}$
1	92	8464	14	604.57	.15	.85
2	92	8464	14	604.57	.15	.85
3	91	8281	14	591.50	.15	.85
4	91	8281	14	591.50	.15	.85

SEASON	(G) TOTAL DAYS D	(H) AVERAGE (FORM 3, (C))	(I) TOTAL (G) x (H)
1	92	8.00	736.00
2	92	4.57	420.44
3	91	6.76	615.16
4	91	5.52	502.32
		ANNUAL OPERATIONS	(J) 2274 (Sum of Col. (I))

SEASON	(K) FROM FORM 3, (V)	(L) $\frac{D^2}{d}$	(M) COLUMN (K) x COLUMN (L)	(N) $1 - \frac{d}{D}$	(O) COLUMN (M) x COLUMN (N)
1	39.00	604.57	23578.23	.85	20041.50
2	18.85	604.57	11396.15	.85	9686.73
3	99.17	591.50	58659.06	.85	49860.20
4	21.68	591.50	12823.72	.85	10900.16
				VARIANCE OF OPERATIONS	(P) 90488.59 (Sum of Col. (O))

t-VALUE CHART
Find Lowest Value of d from Column (C)

If d-1,	then	t
3		3.182
4		2.776
5		2.571
6		2.447
7		2.365
8		2.306
9		2.262
10		2.228
11		2.201
12		2.179
13		2.160.
14		2.145
15		2.131
16		2.120
17		2.110
18		2.101
19		2.093
20		2.086
30		2.042
40		2.021
50		2.009
60		2.000
80		1.990

(Q) $\sqrt{(P)}$	300.81
t-VALUE FROM CHART (R)	2.16
95% CONFIDENCE INTERVAL (S) ± (Q) x (R)	650
PERCENT SAMPLING ERROR (T) ± ((S)÷(J)) x 100	28.6

5. ESTIMATING DISTRIBUTIONS OF OPERATIONS

Often the distribution of operations over various time periods, or by type of operation, is as important as the estimate of total annual operations. An estimate of daily peak operations, for example, is needed to plan for airport capacity improvement projects. For many types of decisions the distribution of operations between local and itinerant operations may be almost as significant as total operations.

Distributions of operations that can be estimated include:

1. Distributions of operations across various time periods, including seasons, months, and weeks;
2. Frequency distributions and peak period estimates, including peak day or hour, and number of days exceeding a specified level of operations; and
3. Distributions of operations by type, including local/itinerant distribution, by aircraft type, and by runway or direction.

Estimate Seasonal and Monthly Distributions

Seasonal distributions may be determined by dividing the estimates of operations for each season by the annual estimate. For example, at Tri-City State Airport estimates of operations in each of the four seasons are 736, 420, 615, and 502, respectively. The seasonal distribution of operations is:

Summer	Fall	Winter	Spring
32%	19%	27%	22%

The distribution of operations indicates summer was the busiest season, as might be expected. The distribution also shows that winter had a larger share of operations than expected. Prior to the sample, winter was thought to have the lowest proportion of annual operations.

If a week of operations counts is obtained in each month, these data may be used to calculate the monthly distribution of operations. Average daily operations for each week sampled is multiplied by the number of days in the month to obtain total operations for the month. For example, at Tri-City State Airport average daily operations for the week sampled in August (10.86) multiplied by the number of days in August (31) equals estimated operations for August (336). Monthly operations estimates are divided by total annual operations to calculate the monthly distribution of operations. The monthly distribution is useful in identifying peak month activity and the range between the high and low activity months. It is not possible to construct a monthly distribution of operations for Tri-City State Airport because sample data was not obtained in all months.

Estimate Frequency Distribution and Peak Operations

If the sample is seasonally proportional, the sample data can be used to estimate the frequency distribution of operations and peak operations. A frequency distribution of daily operations is a tally of how often a given number of daily operations occurred during the sample. For example, it might indicate that 10 percent of the days sampled had 0-10 operations, 15 percent of the days sampled had 11-20 operations, 20 percent of the days sampled had 21-30 operations, etc. The distribution of sampled operations can be assumed to reflect the distribution of all operations.

Peak daily operations is the highest number of operations that was counted during a single day sampled. True peak daily operations will be at least as high as the peak observed from the sample data. There is no statistically reliable way to determine how much higher, if any, the true peak is.

The frequency distribution of hourly operations and peak hourly operations can also be determined in the same manner, if information about time of operation is collected during the sample.

Estimate Distribution of Operations by Type

If information about operations, such as aircraft type, is collected for each operation during the sample, then the distribution of operations by type can be determined in the same manner as the seasonal distribution. For example, at Tri-City State Airport there were 422 total fixed wing operations counted during the sample, which included 346 single engine, 76 multi-engine, and no jet aircraft. The distribution of operations by aircraft type is determined by dividing the operations for each aircraft type by total operations:

Single Engine	Multi-Engine	Jet
82%	18%	0%

Distributions can be calculated in the same way for any characteristic of operations that was collected during the sample.

Often information is desired about operations, but is too costly to collect for every operation counted. For example, identifying operations as local or itinerant is often desired, but requires a costly visual count to obtain the information. If funding is not adequate to conduct the entire sample using visual observation, the sample may be collected using a less expensive method, but augmented with a visual subsample of operations that are identified as local or itinerant. For example, two days out of each week sampled can be randomly subsampled for a visual count of operations. If the split between local and itinerant operations is expected to be different on weekdays and weekends, then both weekdays and weekends should be proportionally included in the visual subsample (e.g., two weekdays and one weekend day). At least two days must be subsampled from each week in order to estimate the precision of the estimate made from the subsample. The same number of days should be subsampled out of each week. The total size of the subsample will vary for the situation. In general, the larger the subsample the more accurate will be the result, but a good rule of thumb is to subsample at least 20 days out of the larger sample.

The proportion of local operations is determined by dividing the number of local operations counted by the total number of operations visually counted in the subsample. The proportion of itinerant operations is found in the same way.

The proportion of local and itinerant operations found in the subsample can then be applied to the larger sample. For example, if the visual subsample indicates 70 percent of the visually counted operations were local and 30 percent were itinerant, then total annual operations estimated from the large sample also can be assumed to be 70 percent local and 30 percent itinerant. The proportion of local and itinerant flights determined from a small subsample should only be applied to annual operations. The same proportional split may not hold for quarterly or monthly operations.

Additional information about this type of subsampling, called subsampling for proportions, can be found in a sampling textbook.[6]

Estimate Distribution of Operations Using Independent Data

If sufficient sample data is not available to directly calculate the seasonal or monthly distribution of operations, then independent data, such as weather, fuel sales, or tower data, may be used as a proxy. It should be noted that independent data is used here to allocate or distribute an estimate of annual operations obtained from sample data collected throughout the year. It is not used to expand one small sample of operations to estimate annual operations, which was identified as an unreliable technique in the introduction.

In order to use independent data to measure the changes in operations by season or month, three conditions must be met. First, there must be a theoretical basis or reason for believing that the independent data is related to operations and varies by month or by season in the same way that operations vary. For example, fuel sales at the airport or weather conditions at the airport can reasonably be expected to relate to operations.

Second, the independent data source must be accurate and complete. For example, fuel sales data may be closely related to operations if all fuel sales are reported and reported for the period in which they occurred. However, if private fuel tanks are used and not reported with fuel sales for the airport, the perceived relationship will not be accurate.

Third, the assumed relationship must be statistically established for the time period for which the distribution is reported. A correlation coefficient is a simple statistical measure of how closely independent data is related to operations. The user determines whether the correlation coefficient is satisfactory; that is, whether the independent data and operations are sufficiently related. The correlation coefficient ranges from -1.0 (independent data and operations move in opposite directions) to +1.0 (independent data and operations move together). The higher the correlation coefficient, the better the relationship.

Once an acceptable correlation has been established, independent data may be used to allocate the annual operations estimate. Fuel sales provide an example of how this is done. The example assumes monthly fuel sales data are available. First, the percent of total annual fuel sales (in gallons) that was sold in each month is calculated. The percent of annual fuel sales that was sold in each month is then applied to total annual operations to estimate operations for each month. For example, if 20 percent of total annual fuel sales occurred in July, then 20 percent of total annual operations would be allocated to July. Monthly operations can be added to derive seasonal operations.

In some cases it may also be possible to use the relationship between independent data and operations to estimate operations during years that sample operations data are not collected. This procedure assumes that the relationship observed between independent data and sampled operations at a particular airport throughout one year, or preferably over a number of years, continues to hold in a subsequent year. For example, the ratio of operations per gallon of fuel sold at an airport is calculated for each month for which there are sample operations counts. Average operations per gallon is then calculated for the year. The average operations per gallon ratio is used to estimate operations in subsequent years by multiplying the ratio times the number of gallons sold in the year being estimated.

[6]For example, see Sampling Techniques, William G. Cochran, Second Edition, pp. 278-279.

6. METHODS OF COLLECTING SAMPLE DATA

There are several methods that have been used to collect sample operations data. These include visual observations, pneumatic tube counters, inductance loop counters, and acoustical counters. Each method has its strengths and weaknesses in terms of accuracy, cost, ease of use, and ability to collect additional information about operations. Methods also differ in their suitability to the particular airport being sampled. Each of the methods is described briefly. More detailed information can be obtained from states identified as using a particular counting method, or from operation manuals available from the manufacturers of the mechanical counters. Table 4 at the end of the chapter provides a summary comparison of the different counting methods.

Visual Observation

Visual observation relies on observers physically present at the airport to count operations. It is the most accurate counting method, subject only to human error. However, observers must be trained to ensure the counts are consistent and complete. While it is possible to conduct visual counts 24 hours a day, it is most feasible to visually count operations during daylight hours, especially if additional information about operations is desired. This limitation may decrease the accuracy of the visual count, unless operations are known to occur only in daylight hours.

Visual observation is a relatively expensive way to collect sample data, since workers must be hired to make the observations. Costs may be reduced if volunteer or low-cost labor is available. However, if volunteer observers are used, it may be difficult to control the consistency and accuracy of the counts.

It is possible to gather a variety of information about operations counted using visual observation. Information can include time of operation, type of operation, or type of aircraft. If additional information is desired, the observer must be trained in how to consistently identify the desired characteristic, such as a local or itinerant flight.

Visual observation is most suitable at airports that have operations concentrated in an 8 to 12 hour daylight period. Airports with multiple or widely spaced runways may require more than one observer, expecially if additional information about operations is being collected.

In spite of its accuracy and ease of use, visual observation has not been widely used. This is because of the high cost for even a small sample of operations. Cost becomes even more critical if a 10 or 12 week sample of operations is required.

Virginia has used visual counts by Civil Air Patrol volunteers. Operations were counted only once a year during peak activity periods. The counts were used to determine the percent change in activity from one year to the next, not to estimate total annual operations.

In 1981 Florida estimated annual operations at 28 airports using visual observation. Two people visually counted operations at each airport from 7 AM to 7 PM on seven consecutive days. The sample data were expanded to estimate annual operations using independent factors, such as based aircraft and fuel sales. Additional information about operations, aircraft, passengers, and weather was also collected during the visual survey.[7]

The cost of Florida's 1981 counting program was about $1,000 to $1,200 per airport. Most of the cost was for the survey crew, but costs also included editing and analysis of the sample data.

Pneumatic Tube Counters

Pneumatic tube, or highway, counters were one of the first mechanical devices used to count aircraft operations. The device consists of a rubber tube attached to a counter. As an aircraft rolls over the tube air pressure registers a count on a paper tape.

Placement of the tube is critical to obtain an accurate count of operations. Because of excessive wear of the tubes when placed across the runway, tubes are often placed across taxiways leading to runways. Therefore, the counts recorded are actually of ground movement to and from runways. When placed on taxiways pneumatic tubes cannot count touch-and-go's or missed approaches. An estimated ratio of touch-and-go operations to counted operations is needed to separately estimate touch-and-go's from the counter operations data. This limitation reduces the accuracy of pneumatic tube counts. When tubes are placed across the runway, they still may not count all operations. Usefulness of pneumatic tube counters is further reduced because they cannot distinguish between type of operation and between aircraft and non-aircraft vehicles.

Pneumatic tube counters cost about 30 cents a foot for the rubber tube, plus $110 to $1,900, depending on the sophistication of the counter that is hooked to the tube. The least expensive counter registers counts with about a four percent error. This is a measure of mechanical error and is in addition to the error due to limitations from the placement of the tube and interpretation of the counter data. The more expensive counters register counts with less than a one percent error and provide day and time of count as well. The total cost of counting operations at an airport using pneumatic tubes depends on the number of runways and taxiways that must be counted.

[7] Florida Airport Activity Survey 1981, Division of Planning, Florida Department of Transportation.

Texas used pneumatic tube counters in 1972 and 1973 to count operations during two to three-week sample periods. Tower operations data were used to expand the sample data to estimate annual operations. Touch-and-go operations were estimated separately, based on an estimate by the airport manager of daily touch-and-go's. Texas has since discontinued the use of pneumatic tube counters.[8]

Michigan has used the Abrams Aircraft Counter for 20 years. The pneumatic tubes are placed across taxiways leading to runways. The Abrams Counter counts movement in one direction only and is set to count aircraft taxiing to the runway for departure. Registered counts are doubled to represent total operations. About 40 airports are counted each year. Each airport is counted for six to eight consecutive weeks during the spring, summer, or fall. The sample data is expanded using "M" factors to estimate total annual operations. "M" factors were calculated during the mid-1960's from tower operations data to account for the seasonal fluxuation in annual operations. Since touch-and-go's cannot be counted directly, they are estimated to be 35 percent of the total counted operations and are added to the counter operations estimate. The total annual estimate is then split between itinerant and local operations using a standard 35/65 percent split, unless the airport manager provides a more accurate ratio.[9]

Michigan is planning to count ten control airports every year using new Golden River counters attached to inductance loops permanently installed in the taxiway or runway. Operations will be counted continuously at these ten airports.

The 23 new Golden River counters were purchased at a total cost of $50,000. Airports counted with the Abrams counters cost an average of $360 each to count, including $210 for field and office staff time and $150 for maintenance of the counters.

Inductance Loop Counters

The inductance loop is another type of highway counter that has been used to count aircraft activity. Unlike the pneumatic tube, which is portable, the wire inductance loop is installed in the pavement of the runway or taxiway. It can be attached to the same type of counter device as used with the pneumatic tube. Operations are counted electronically as aircraft roll over the loop or fly over the loop within three feet of the surface. Loops can encompass a maximum of 180 square feet of surface area in which aircraft can be counted.

[8]Annual Aircraft Terminal Operations Counting Program for Nontower Airports, Texas Airport System Plan, Technical Note GA-7, C. Jay Lyons and Robert J. Hammons, 1973; A Method of Expanding a Short Terminal Airplane Operation Count at Nontower General Aviation Airport to an Annual Estimate, Texas Airport System Plan, Technical Note GA-12, C. Jay Lyons, 1973.

[9]Michigan Aircraft Traffic Counter Program, Michigan Department of Transportation, April 1984.

Like the pneumatic tube, correct placement is critical to obtain accurate counts. Even though the loop may be placed directly on the runway, the same limitations of pneumatic tubes exist with loops: they cannot count missed approaches, they likely will not count all touch-and-go's, they cannot distinguish between aircraft and other vehicles on the runway, and they cannot distinguish between landings and departures. Count accuracy could be improved by using a number of loops on the runway and on access taxiways; however, the cross-interpretation of data from all counters would be complex. Given the potential for missed operations and incorrect interpretation of the counts obtained, the suitability of the inductance loop is limited to short runways with limited access. Even in this case not all touch-and-go operations may be counted.

An inductance loop costs about $630, including installation, plus $110 to $1,900 for the counter device, depending on its sophistication. Increased runway maintenance costs are also incurred because of increased deterioration of the runway pavement around the area of installation.

Massachusetts has used inductance loop counters. The loops were believed to be at least as accurate as pneumatic tubes and more durable. Loops were installed 700 to 800 feet from each end of the runways in an attempt to count most landings and departures. Loops were initially installed only on the runway, but it was recognized that counts could be improved if loops or rubber tubes were also placed across access taxiways.[10]

Acoustical Counters

Acoustical counters use a microphone near the runway to pick up the sound of a departing aircraft at full engine power. The sound is recorded by a tape recorder and registered on a digital counter or a microprocessor memory. The recorded tape is then edited to pick out only the sounds of aircraft departures, including touch-and-go's and missed approaches. Departures are doubled to represent total operations. Total operations are not counted directly because quiet landings normally are not picked up by the microphone.

Acoustical counters are capable of accurately recording all departures if they are placed along the runway within their performance standards. Performance standards are adequate for most general aviation airports. If they are placed too far away from the path of departing aircraft, they may not record the departure or not record it distinctly.

Although the acoustical counter accurately records aircraft sounds, the correct interpretation of the recordings is necessary to ensure accurate operations counts. Interpretation of the recordings is necessary to ensure all the departures recorded are identified and counted as departures, but that non-departure sounds are not

[10]Status Report and Analysis of Inductance Loop Counting Method at Lawrence Municipal Airport, Massachusetts Aeronautics Commission, July1977.

mistaken for departures. With minimal training a person can distinguish between departures and other aircraft sounds and identify the type of aircraft departing, such as single engine, multi-engine, or jet. Helicopters can be detected by the counter, but operations cannot be estimated from the recorded sound of the helicopter. In addition to type of aircraft, day and hour of departure can also be determined from hourly time tones on the recorded tape.

The acoustical counter is relatively easy to use and is suitable for use at most airports (with up to 6,000-foot long runways). Some training is necessary on the operation of the counter and the optimal location of the counter near the runway. The counter is self-contained and weather resistant and may be left at an airport for several weeks to continuously count operations. Counters cost about $3,900.

Oregon has been testing and using acoustical counters since 1978. The counter is used to take week-long sample counts 4 to 12 times a year at each airport, depending on the activity level of the airport. The sample data is used to estimate annual, quarterly, and in some cases monthly, operations using standard statistical methods. One counter is rotated among several airports to maximize the use of each counter. Thirty-seven airports were counted during two years of sample counts.[11]

Airports cost an average of $1,200 each to count, including wages and mileage expenses; supplies; maintenance and repair of the counters; allocated capital cost of the counters; interpretation of the recorded tapes; data processing and analysis; and management of the program. Small and remote airports are the most expensive to count because they require a larger sample size, longer driving time and higher mileage costs.

Utah is conducting a counting program similar to Oregon's. One week sample counts are taken during each season of the year. The sample data is expanded statistically to obtain annual operations estimates. During the 1983-84 counting period, six airports were counted with one counter. Total cost to collect the sample data and estimate annual operations was $17,189, or an average of $2,865 per airport. This does not include the cost of the counter, which was $3,225. Utah plans to count 18 airports with three acoustical counters during 1984-85. Estimated cost is $30,497, or $1,694 per airport, not including the cost of the counters.[12]

Arizona contracted with a consultant to count 30 airports and estimate annual operations in 1982-83. Six acoustical counters were used, which are owned by the consultant. Operations were counted during a two-week sample period. The sample data was expanded to an annual estimate of operations based on fuel sales (in dollars). The ratio of annual fuel sales during the previous year to fuel sales during the sample period is multiplied by the sample operations to obtain annual operations. For airports that did not have fuel sales or other independent data available, a linear projection of the sample data was made to estimate annual operations.[13]

Arizona's total cost of the count was $12,000, or $400 per airport. However, the consultant's actual cost to count 30 airports was $30,000, or $1,000 per airport.

[11] Aircraft Activity Counter Demonstration Project, Final Report, Aeronautics Division, Oregon Department of Transportation, 1982; Unpublished reports of airport operations estimates, Oregon Department of Transportation, 1984.

[12] Utah State Airport System Plan Update-1981 (with revisions), Utah Department of Transportation, 1984.

[13] Arizona Airport Activity Survey 1982-83 of 30 General Aviation Airports, Vol. I Observations and Projections, Transportation Planning Division, Arizona Department of Transportation, June 1983.

Table 4. Comparison of Alternative Counting Methods

	Visual	Pnuematic Tube and Inductance Loops	Acoustical Counters
Ability to Count:			
Total Operations	Very accurate	Counts only operations that cross tubes	Counts fixed-wing take-offs,including touch-and-go's
Local/Itinerant Operations	Can be distin-guished by trained observers	Cannot be distinguished	Cannot be distinguished
Aircraft Type	All classes can be distinguished	Cannot be distinguished	Distinguishes major classes: singles, multi's, jets and helicopters
Unit Cost	Not applicable	Up to $2,530. An airport may re-quire more than one unit. Units can be rotated among airports	About $3,900. Units can be rotated among airports
Operating Cost	Very high if observers are paid	Relatively low	Relatively low
Major Advantage Compared to Other Methods	Very accurate. Can identify a variety of information about operations	Inexpensive	Inexpensive and more accurate than pnuematic tube
Major Disadvantage Compared to Other Methods	High cost	Least accurate. Only counts operations that cross tube or loop	Requires interpretation of recorded sounds

APPENDIX A
CORRECTIONS FOR LOSS OF SAMPLE DATA

The purpose of this appendix is to provide procedures for use when data are incomplete. When the sampling plan is developed as recommended and followed as closely as possible, problems interpreting data should be minimal. However, there are several problems that may occur as a result of loss of data. Lost data may result in incomplete clusters (normally weeks) or loss of entire clusters. Loss of entire clusters will eliminate proportionality of the sample and may leave a season with only one cluster of data from which to determine operations and variance. As long as there is at least one cluster or combination of incomplete clusters containing both weekdays and weekend days in each season, the data can be salvaged and a statistically valid operations estimate with a known degree of precision can be calculated.

Incomplete Clusters

As discussed previously, the use of week-long clusters eliminates biases that would otherwise result from weighting certain days of the week more heavily. Incomplete clusters may be used in calculation of annual and seasonal operations for an airport, but they must receive special treatment to ensure that biases are not reintroduced into the statistics.

If the cluster contains both weekdays and weekend days, then a fairly simple calculation, described in Alternate Procedure 1 at the end of this section, can be used to calculate several of the boxes in Forms 2 and 3. Once these calculations are made the remainder of the calculations can proceed.

If the cluster does not contain both weekdays and weekend days, then the daily operations data from that cluster will either have to be eliminated from consideration or combined with other cluster data. If the season in which the incomplete cluster lies already has two complete clusters, it will usually be best to discard the incomplete cluster and continue with calculations. If there are not two other complete clusters in the season, it may be desirable to combine all clusters in the season and calculate the seasonal average and variance as though the data came from a stratified random sample. Procedures for this type of calculation are contained in Alternate Procedure 2 at the end of this section. It will be necessary to have at least two weekdays and two weekend days represented in the combined sample in order to make calculations and to minimize inaccuracies. The results for the season can be entered on Form 4 to complete calculations of annual total operations and the sampling error.

If data within any one season is severly limited, as in the case of only one incomplete cluster, it may be appropriate to consider redefining seasons as described in Alternate Procedure 3, before using Alternate Procedure 2.

If, within any season, there are no clusters or combination of clusters containing both weekdays and weekend days, a statistically valid estimate of annual operations cannot be calculated for the airport.

Loss of Clusters

If whole clusters are lost or discarded, the sample may no longer be representative of the entire year and it may not be possible to complete a calculation of annual operations and the sampling error as described in the previous section.

If, after the loss of a cluster, there remains in each season at least two clusters containing both weekdays and weekend days, any bias introduced by the loss of the data will be so insignificant that calculations can continue using the standard procedures.

If some seasons are left with only one cluster, there are three options that may be pursued. The first option may be used only if clusters are evenly spaced throughout the year. If they are, then total annual operations and the sampling error may be calculated without stratifying by season, since proportionality of data will automatically reflect seasonal factors. These calculations are carried out with the standard forms as though all data came from one year-long season.

The second option is to redefine seasons as described in Alternate Procedure 3. If seasons can be redefined so that each season contains at least two clusters, then the standard procedures may be used to complete calculation of total operations and the sampling error.

If an attempt to redefine seasons is unsuccessful, then the third option is to use Alternate Procedure 4 to calculate average daily operations and variance for seasons with only one cluster. The results of this procedure can be used in Form 4 to complete standard calculations.

If some seasons are left with no clusters or combination of clusters containing both weekdays and weekend days, and if seasons cannot be redefined to eliminate the situation, then no statistically valid estimate of operations can be made for the airport.

INSTRUCTIONS FOR ALTERNATE PROCEDURE 1

This procedure is used to calculate intra-cluster average daily operations and variance for clusters not containing seven days. This procedure can be used only if the incomplete cluster contains both weekdays and weekend days. It can be adapted for any situation in which the cluster is not a multiple of seven days, including clusters of more than seven days.

To apply Alternate Procedure 1 use Worksheets 2a and 3a to calculate adjustments to Forms 2 and 3, respectively. Once these adjustments are made calculations may continue according to standard procedures.

Worksheet 2a: The purpose of this worksheet is to calculate an unbiased estimate of average daily operations for a week when the sample cluster is incomplete. (If the cluster consists of a full seven days, these calculations will yield exactly the same result as using Form 2 directly.)

Column (A) Enter total operations counted for each weekday sampled. There must be one or more entries in this column and it may have more than five entries if data cover a period longer than one week.

Box (B) Sum column (A) and enter the answer in box (B).

Box (C) Enter the number of weekdays sampled, normally between 1 and 5.

Box (D) Divide the sample total, box (B), by the number of weekdays sampled, box (C), and enter the answer in box (D).

Box (E) Multiply weekday average operations, box (D), by 5 and enter the answer in box (E). The purpose of this calculation is to develop a proportion. Therefore, it is correct to multiply by 5 even if the cluster covers a period of more than one week.

Column (F) Enter total operations for each weekend day sampled. There must be at least one entry in this column. If the cluster is more than one week, there may be more than two entries.

Box (G) Sum column (F) and enter the answer in box (G).

Box (H) Enter the number of weekend days sampled, normally 1 or 2.

Box (I) Divide the sample total, box (G), by the number of weekend days sampled, box (H), and enter the answer in box (I).

Box (J) Multiply weekend day average operations, box (I), by 2 and enter the answer in box (J). The purpose of this calculation is to develop a proportion. Therefore, it is correct to multiply by 2 even if the cluster covers a period of more than one week.

Box (K) Add box (E) and box (J) and enter the answer in box (K).

Box (L) Divide box (K) by 7 and enter the answer in box (L). This is the average daily operations for the week or weeks represented by the cluster sample. This number is transferred to Form 2, box (D).

WORKSHEET 2A
CALCULATION OF AVERAGE DAILY OPERATIONS FOR FORM 2

WEEK DAY	(A) WEEKDAY OPERATIONS
1	
2	
3	
4	
5	

WEEKEND DAY	(F) WEEKEND OPERATIONS
1	
2	

SAMPLE TOTAL	(B) Sum Col. (A)	SAMPLE TOTAL	(G) Sum Col. (F)
WEEKDAYS SAMPLED	(C)	WEEKEND DAYS SAMPLED	(H)
WEEKDAY AVERAGE	(D) (B) ÷ (C)	WEEKEND DAY AVERAGE	(I) (G) ÷ (H)

(E) (D) x 5 + (J) (I) x 2 = (K) (E) + (J)

AVERAGE DAILY OPERATIONS (L) (K) ÷ 7

Transfer to Form 2. Box (D)

INSTRUCTIONS FOR ALTERNATE PROCEDURE 1, continued

Worksheet 3a: The purpose of this worksheet is to calculate "M" for use in Form 3, Seasonal Data, when Alternate Procedure 1 has been used to calculate the average daily operations for any of the sample clusters within the season represented by Form 3. "M" will be the average number of days per cluster.

Box D	Fill in the total number of days in the season.
Box d	Fill in the total days sampled in all clusters within the season.
Box n	Fill in the number of clusters sampled within the season. This number is transferred to the box n at the top of Form 3.
Box M	Divide d by n and enter the answer in box M. The result is the average days per cluster, M, and is transferred to the box M at the top of Form 3.
Box N	Divide D by M and enter the answer in box N here and at the top of Form 3.

When Worksheet 3a is used, the total number of clusters in the season in box N at the top of Form 3, will depend on the average size of the cluster, M. That is, N is determined by the total days in the season divided by M.

WORKSHEET 3A
CALCULATION OF M FOR FORM 3

TOTAL DAYS IN THE SEASON	D	
TOTAL DAYS SAMPLED IN THE SEASON	d	
NUMBER OF CLUSTERS SAMPLED IN THE SEASON	n	
AVERAGE DAYS PER CLUSTER	M d ÷ n	→ Enter as value for M in Box at top of Form 3
TOTAL CLUSTERS IN THE SEASON	N D ÷ M	

INSTRUCTIONS FOR ALTERNATE PROCEDURE 2

This procedure is used to calculate average daily operations and variance for a season in which there are incomplete clusters. The procedure combines all daily operations data in the season into a single sample, stratified by weekdays and weekend days. Application of the procedure requires that there be at least two weekdays and two weekend days sampled in the season.

The following steps are needed for alternate procedure 2:[14]

1. Calculate the average daily operations for all weekdays, $\bar{y}_d$.

2. Calculate the sample variance for average daily operations for weekdays, $s^2(\bar{y}_d)$.

3. Calculate the average daily operations for all weekend days, $\bar{y}_e$.

4. Calculate the sample variance for average daily operations for weekend days, $s^2(\bar{y}_e)$.

5. Calculate the average daily operations for the entire season, $\bar{y}_{st}$, according to the formula:

   $$\bar{y}_{st} = \frac{5(\bar{y}_d) + 2(\bar{y}_e)}{7}$$

   Enter this number in Form 4, column (H).

6. Calculate the variance of average daily operations for the entire season, $s^2(\bar{y}_{st})$, according to the following formula:

   $$s^2(\bar{y}_{st}) = s^2(\bar{y}_d)\left(\frac{.5102}{n_d} - \frac{.7143}{N}\right) + s^2(\bar{y}_e)\left(\frac{.0816}{n_e} - \frac{.2857}{N}\right)$$

   Where:

   n_d = number of weekdays sampled in the season,
   n_e = number of weekend days sampled in the season, and
   N = total days in the season, both weekdays and weekend days.[15]

   Enter this number in Form 4, column (K).

[14] These steps require some knowledge of statistics to follow. If necessary, consult a basic statistics book for formulas to calculate averages and sample variances. With these two pieces of information the remaining calculations are straightforward.

[15] Cochran, pp. 93-94.

INSTRUCTIONS FOR ALTERNATE PROCEDURE 3

This procedure is used to redefine seasons. When some seasons are left with only a single data cluster it may be appropriate to consider ways to redefine seasons (post stratify data) so that each will have more than one cluster. This will permit the use of standard procedures for the calculation of annual operations and the sampling error.

First use Form 2 (or Alternate Procedure 1, if necessary) to calculate average daily operations for each cluster.

Based on expected seasonal variations and knowledge of the average daily operations of the various clusters, try to group consecutive months into seasons to minimize known and expected differences in daily operations. If post stratified data result in two clusters per season, then the standard procedures can be used to complete calculations of annual operations and the sampling error.

If it is not possible to logically redefine seasons to contain at least two clusters, and clusters are not evenly spaced throughout the year, use Alternate Procedure 4 to calculate average daily operations and variance for the season. If clusters are evenly spaced throughout the year, then it may be appropriate to calculate annual operations without seasonal statifications.

INSTRUCTIONS FOR ALTERNATE PROCEDURE 4

This procedure is used to calculate the sampling error when one or more seasons contain only one cluster. As discussed above, if some seasons contain only one cluster, the variance of the season cannot be calculated. On the other hand, if sample clusters are not evenly spaced throughout the year, seasonal estimates must be used in the calculation of total annual operations to avoid biasing the results. The solution to this dilemma is to use seasonal stratifications to calculate total annual operations, but combine all cluster data without regard to seasons to estimate the sampling error. In this case the estimate of total annual operations will usually be more precise than indicated by the sampling error.

The following steps are needed for Alternate Procedure 4:

1. Complete a Form 2 for each cluster.
2. Estimate average daily operations for each season using Form 3, column (A) and boxes (B) and (C). It is not necessary to complete all of Form 3 during this step.
3. Use Form 4, columns (G), (H), and (I), and box (J) to calculate total annual operations. It is not necessary to complete all of Form 4 during this step.
4. Divide total annual operations by 365 to get average daily operations for the year. Enter this number in box (C) of a new Form 3.
5. Fill in columns (A) and (K) of the new Form 3, combining all information from the previously completed Form 2's into a single Form 3 without regard to seasons.
6. Complete the new Form 3 using information recorded in columns (A) and (K) and box (C), and ignoring box (B). Enter the results of this calculation, box (V), into a new Form 4, column (K).
7. Enter the number from box (J) of the previously completed Form 4 in box (J) of the new Form 4. Enter 365 in column (A). Enter total days sampled for the entire year in column (C).
8. Complete the new Form 4 as though all data came from a single season to calculate the sampling error for the annual operations estimate.

APPENDIX B

STATISTICAL DERIVATION OF ESTIMATING PROCEDURES

The statistical equations below were used to develop the forms in Chapter 4. People familiar with statistical estimating procedures may find it easier to use the statistical equations than the forms. The estimating equations are appropriate for a stratified cluster sample. Cluster units are weeks; elements of the cluster are days.

Estimate of Annual Operations

Operations are first calculated for each stratum, h, then added for total annual operations.

For each stratum, h:

$$\bar{y}_i = \frac{\sum^{M_i} y_{ij}}{M_i}, \text{ where}$$

$\bar{y}_i$ = mean operations per day in the ith cluster,
y_{ij} = operations on the jth day in the ith cluster,
M_i = number of elements in the ith cluster.

$$\bar{y}_h = \frac{\sum^{n_h} \bar{y}_i}{n_h}, \text{ where}$$

$\bar{y}_h$ = mean operations per day in stratum h,
n_h = number of clusters sampled in stratum h.

$$\hat{Y}_h = \bar{y}_h D_h, \text{ where}$$

$\hat{Y}_h$ = estimated operations in stratum h,
D_h = total number of days in stratum h.

$$\hat{Y}_{st} = \Sigma \hat{Y}_h, \text{ where}$$

$\hat{Y}_{st}$ = total estimated annual operations from a stratified sample.

Estimate of Variance

The variance of operations in each stratum is estimated. Strata variance are then added for the estimate of variance of total annual operations.

For each stratum, h:

$$s_h^2 = \frac{(N_h - 1)\, s_b^2 + N_h (M_h - 1)\, s_w^2}{N_h M_h - 1}, \text{ where}$$

s_h^2 = estimated variance of stratum h,
N_h = number of clusters in stratum h,
M_h = number of elements in clusters in stratum h (if cluster size varies within the stratum, then M_h can be approximated as $M_h = \frac{\sum^{n_h} M_i}{n_h}$),

$$s_b^2 = \frac{\Sigma(\bar{y}_i - \bar{y}_h)^2}{n_h - 1} = \text{variance between clusters in stratum h,}$$

$$s_w^2 = \frac{\sum^{n_h} \sum^{M_h} (y_{ij} - \bar{y}_i)^2}{n_h (M_h - 1)} = \text{variance between elements within clusters in stratum h.}$$[16]

Once s_h^2 is estimated for each stratum, it is expanded in the standard manner to estimate the variance of estimated operations for each stratum, h:

$$S^2(\hat{Y}_h) = \frac{N_h^2\, s_h^2}{n_h}(1 - f), \text{ where}$$

$S^2(\hat{Y}_h)$ = estimated variance of estimated operations in stratum h,
N_h = number of days in stratum h,
n_h = number of days sampled in stratum h,
$(1 - f)$ = finite population correction (fpc) factor ($f = \frac{n_h}{N_h}$). Fpc can be ignored if $f < 5\%$.[17]

For the variance of total annual operations:

$$S^2(\hat{Y}_{st}) = \Sigma S^2(\hat{Y}_h), \text{ where}$$

$S^2(\hat{Y}_{st})$ = estimated variance of estimated annual operations from a stratified sample.

[16] The variance equations are based on the discussion of analysis of variance for cluster samples in Cochran, pp. 239-241; and in Sampling Theory of Surveys With Application, P. V. Sukhatme and B. V. Sukhatme, Second Edition, pp. 222-227 and 231-232.

[17] Cochran, p. 25.

Confidence Interval

The confidence interval of the estimated annual operations is:

$$\hat{Y}_{st} \pm t_{a/2} \sqrt{S^2(\hat{Y}_{st})}\text{, where}$$

$t_{a/2}$ = t-value at the a/2 probability level with n-1 degrees of freedom.

In a stratified sample, the degrees of freedom, (n-1), for choosing t will differ if the sample size differs among strata. Form 4 uses a conservative estimate of n-1 (noted as d-1 on Form 4) by using the lowest number of days sampled in any one stratum. Actually, the number of degrees of freedom will lie between the smallest value of (n_h -1) and their sum. The equation for calculating the effective number of degrees of freedom, n_e, is:

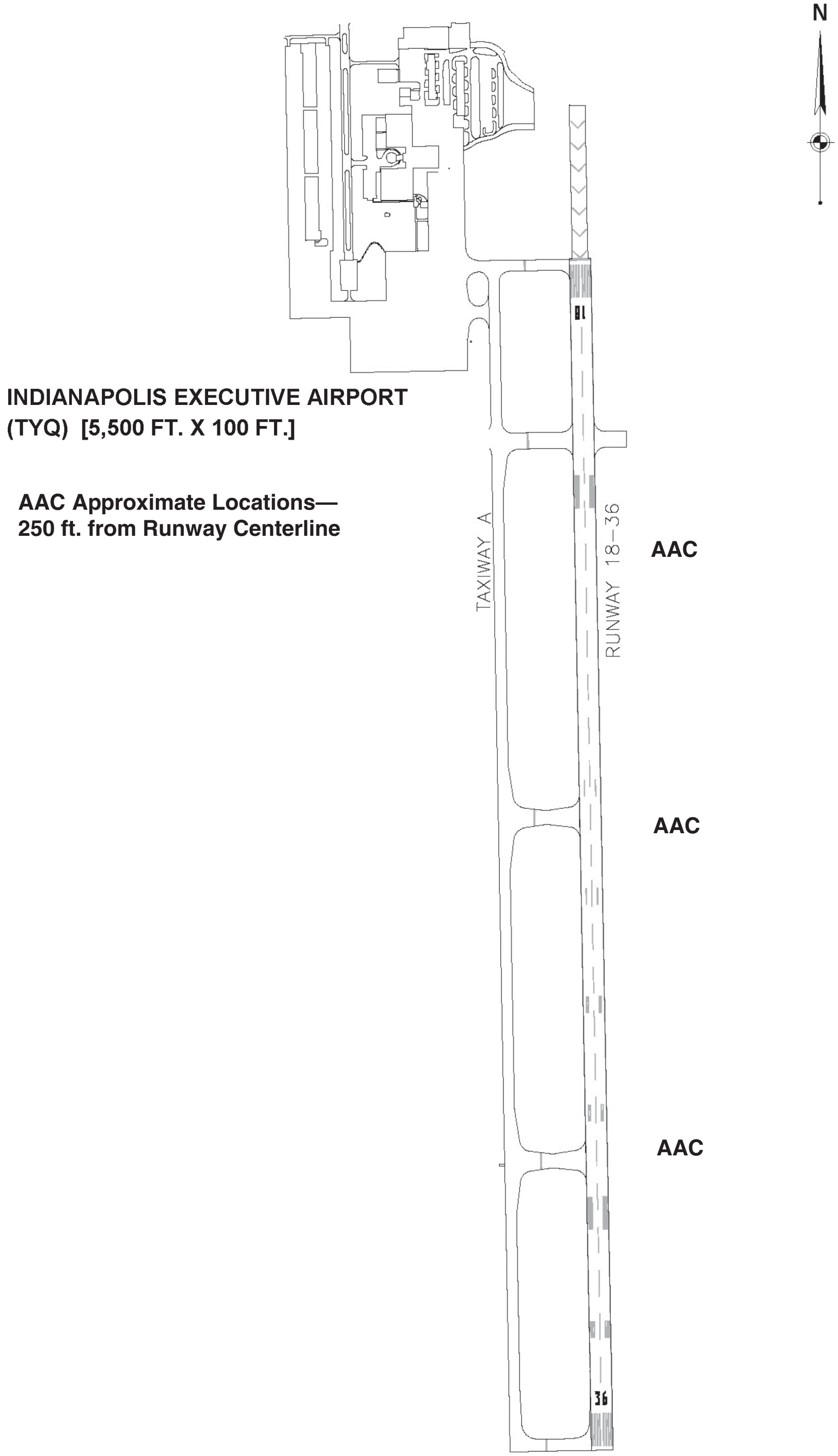
$$n_e = \frac{(\Sigma g_h s_h^2)^2}{\Sigma \frac{g_h^2 s_h^4}{n_h - 1}}\text{, where}$$

$$g_h = \frac{N_h (N_h - n_h)}{n_h}.$$[18]

[18]Cochran, pp. 94-95.

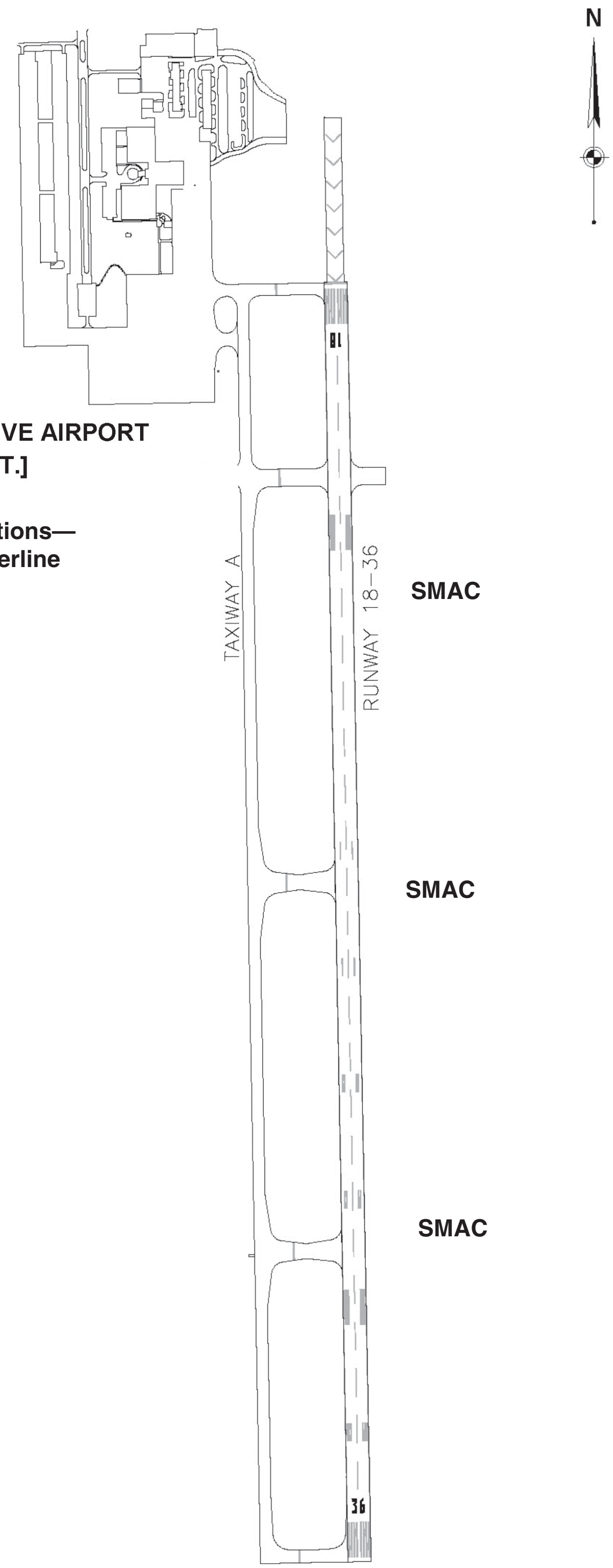
APPENDIX D

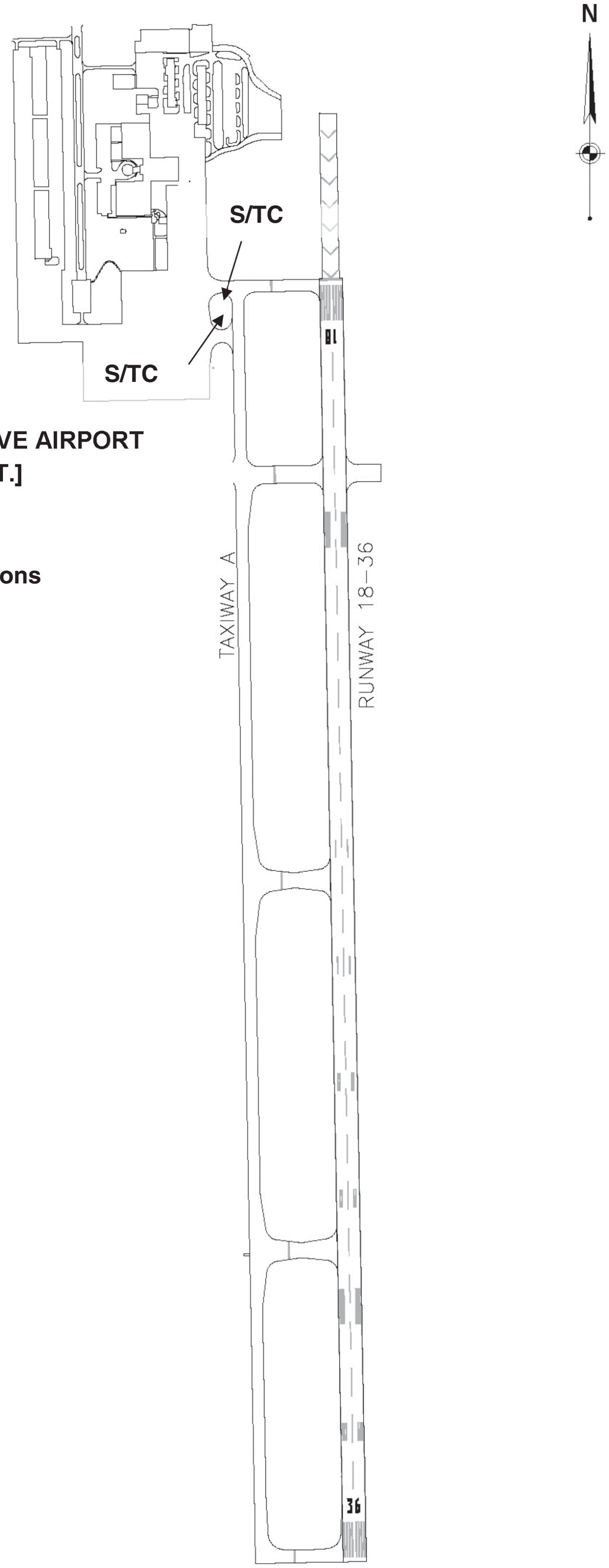
Airport Diagrams


N
INDIANAPOLIS EXECUTIVE AIRPORT
(TYQ) [5,500 FT. X 100 FT.]
AAC Approximate Locations—
250 ft. from Runway Centerline
TAXIWAY A
RUNWAY 18–36
18
36
AAC
AAC
AAC

INDIANAPOLIS EXECUTIVE AIRPORT
(TYQ) [5,500 FT. X 100 FT.]

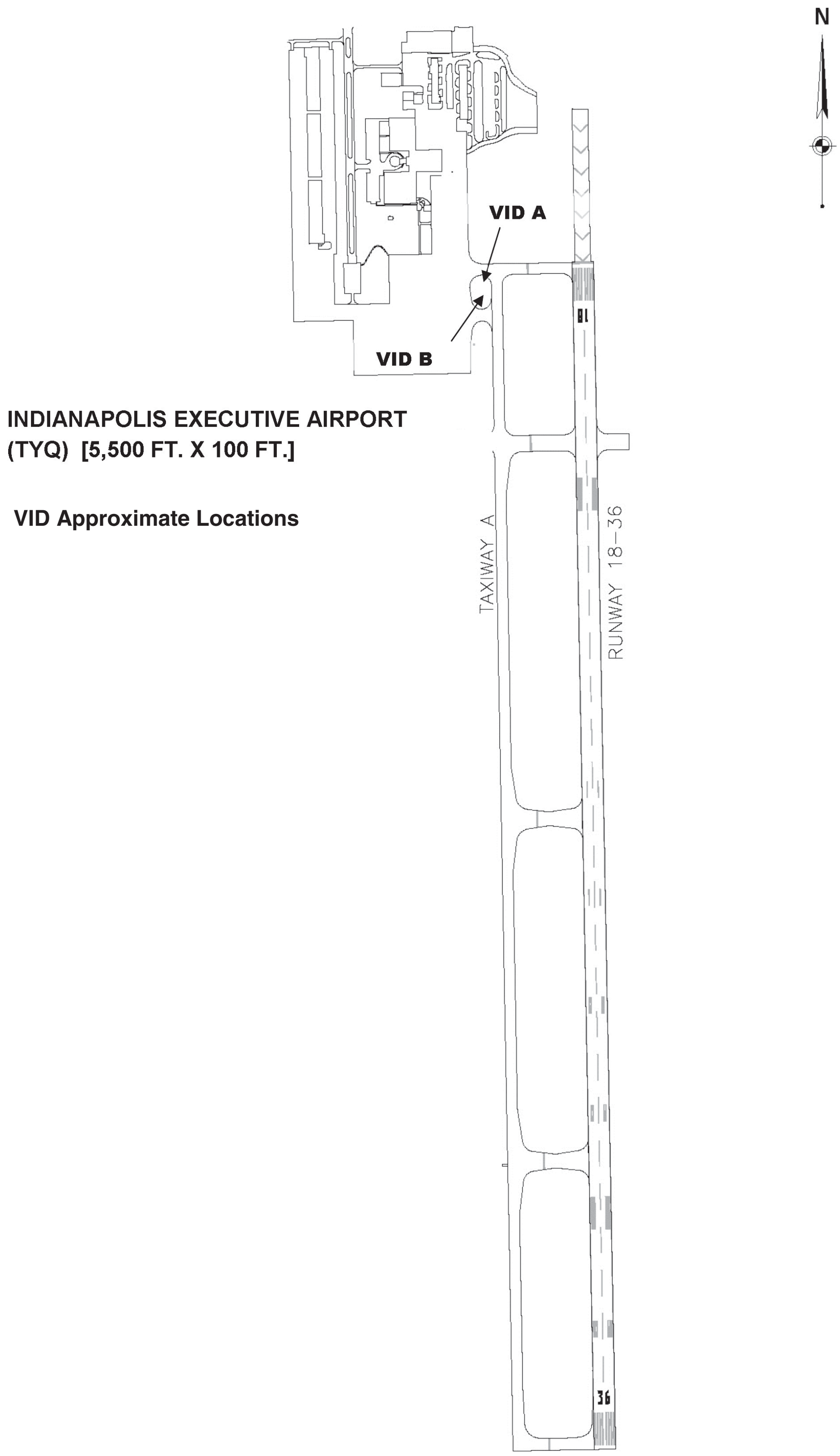
SMAC Approximate Locations—
250 ft. from Runway Centerline





INDIANAPOLIS EXECUTIVE AIRPORT (TYQ) [5,500 FT. X 100 FT.]

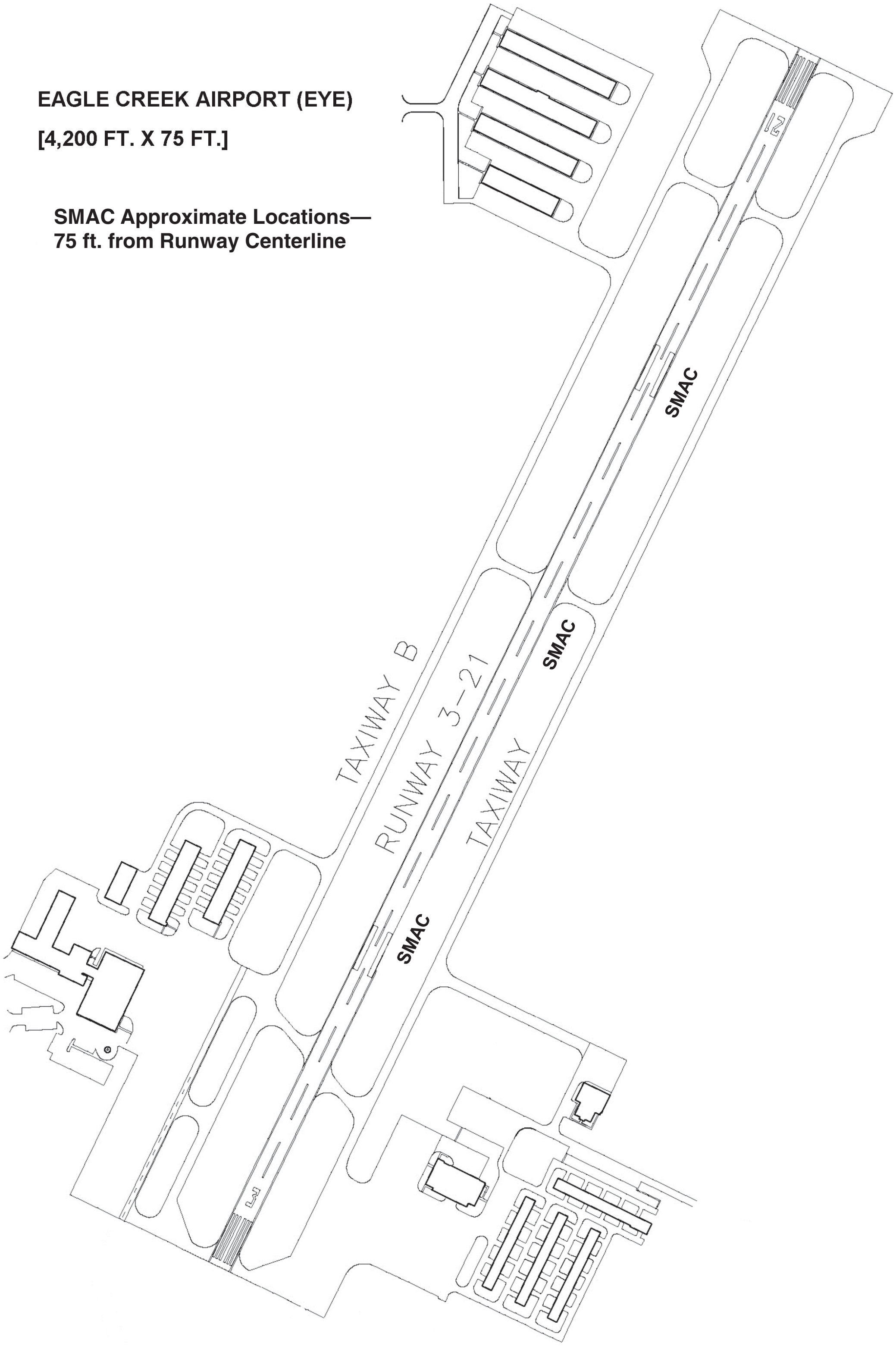
S/TC Approximate Locations

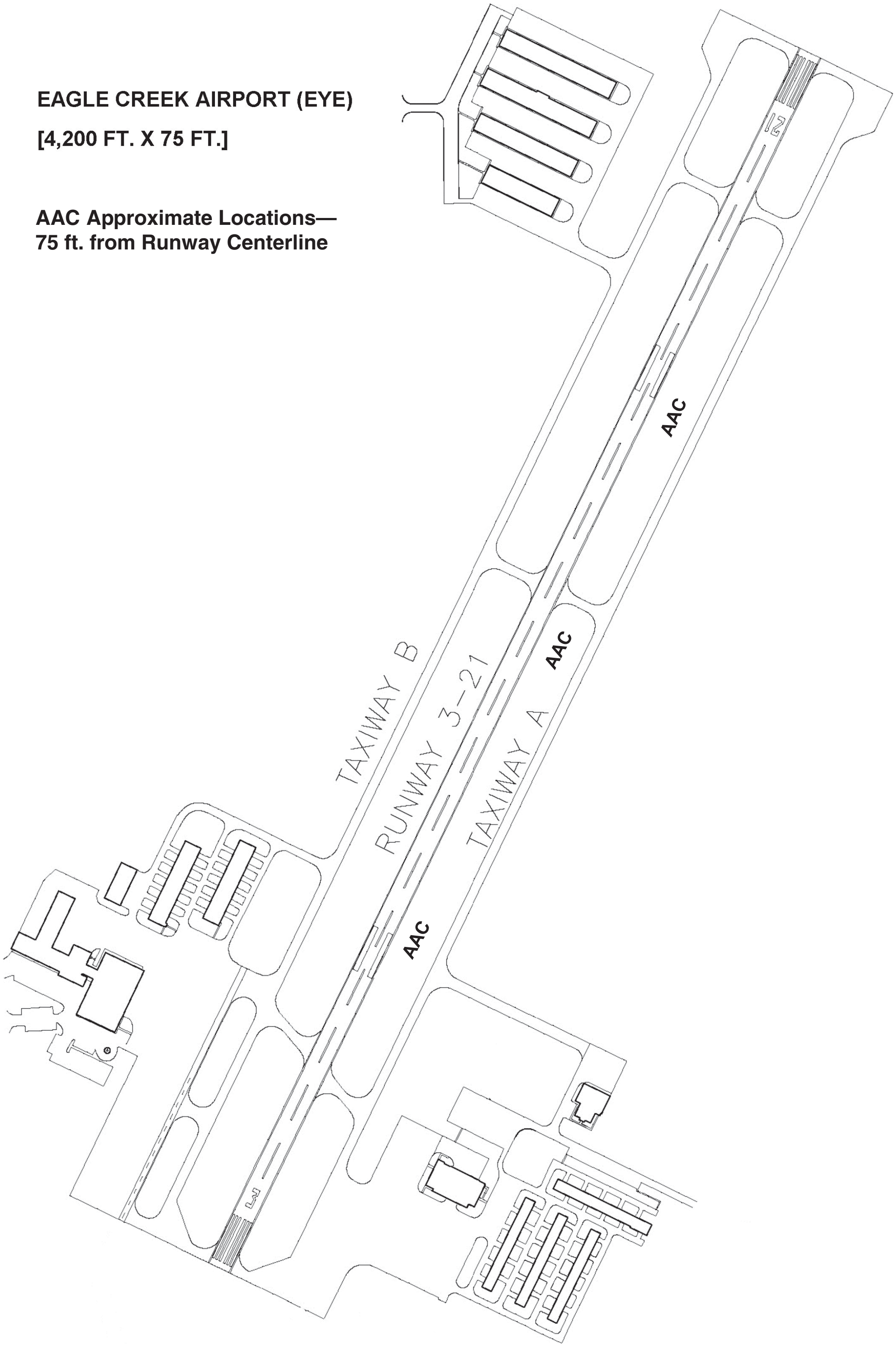

N
VID A
VID B
INDIANAPOLIS EXECUTIVE AIRPORT
(TYQ) [5,500 FT. X 100 FT.]
VID Approximate Locations
TAXIWAY A
RUNWAY 18–36
18
36

EAGLE CREEK AIRPORT (EYE)

[4,200 FT. X 75 FT.]

SMAC Approximate Locations— 75 ft. from Runway Centerline

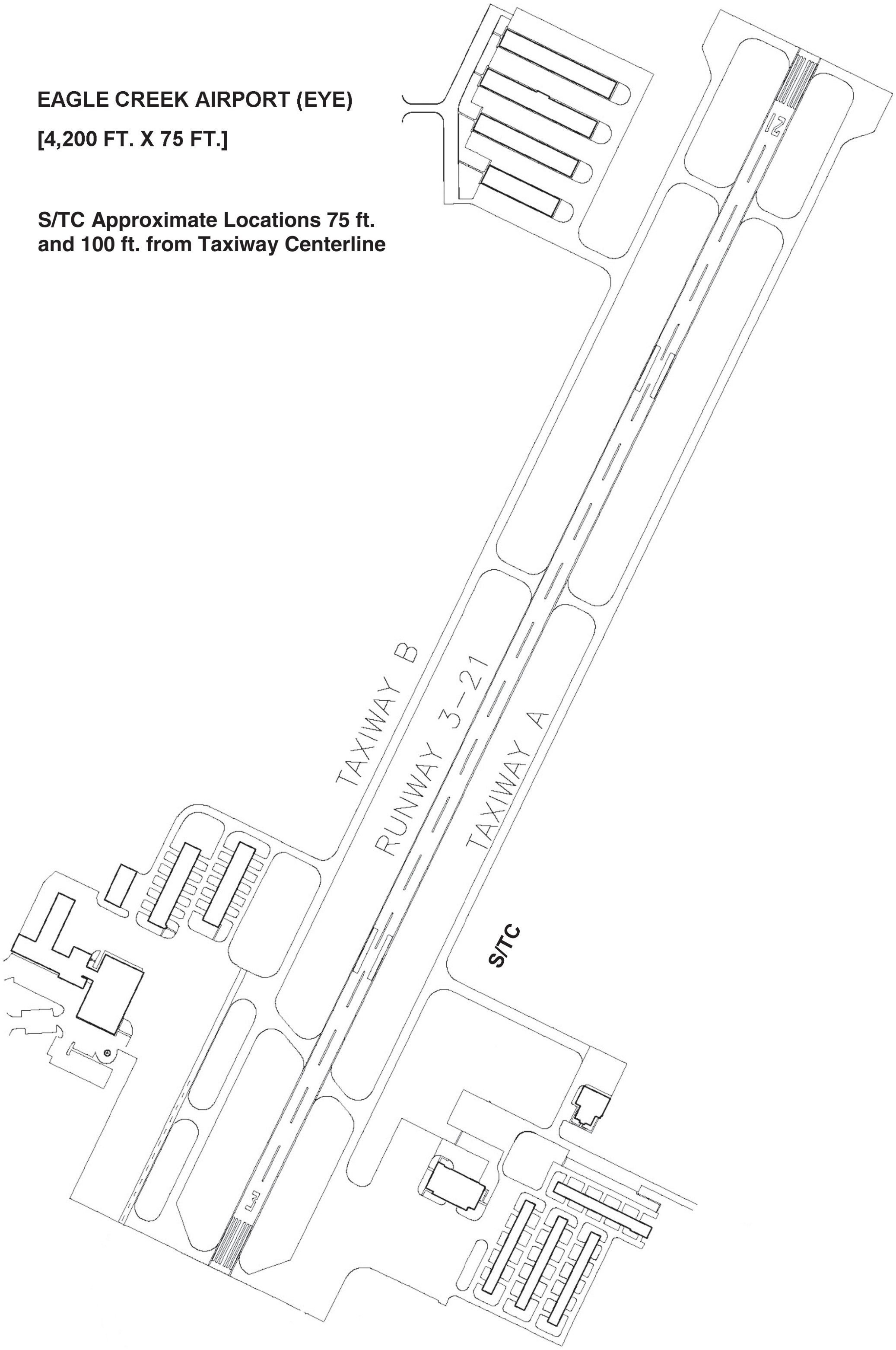


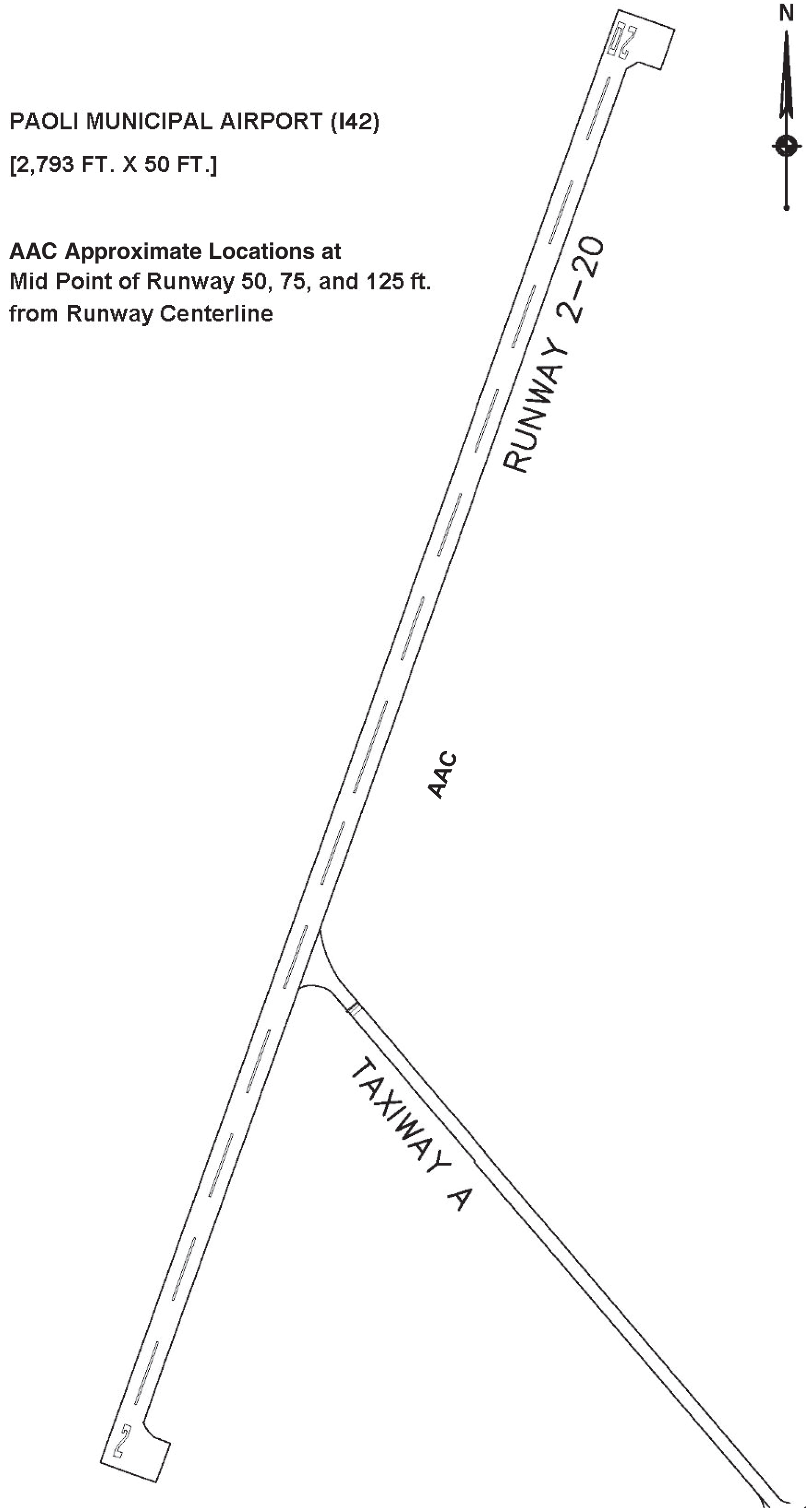

EAGLE CREEK AIRPORT (EYE)
[4,200 FT. X 75 FT.]
AAC Approximate Locations—
75 ft. from Runway Centerline
AAC
AAC
AAC
TAXIWAY B
RUNWAY 3–21
TAXIWAY A

EAGLE CREEK AIRPORT (EYE)

[4,200 FT. X 75 FT.]

S/TC Approximate Locations 75 ft. and 100 ft. from Taxiway Centerline

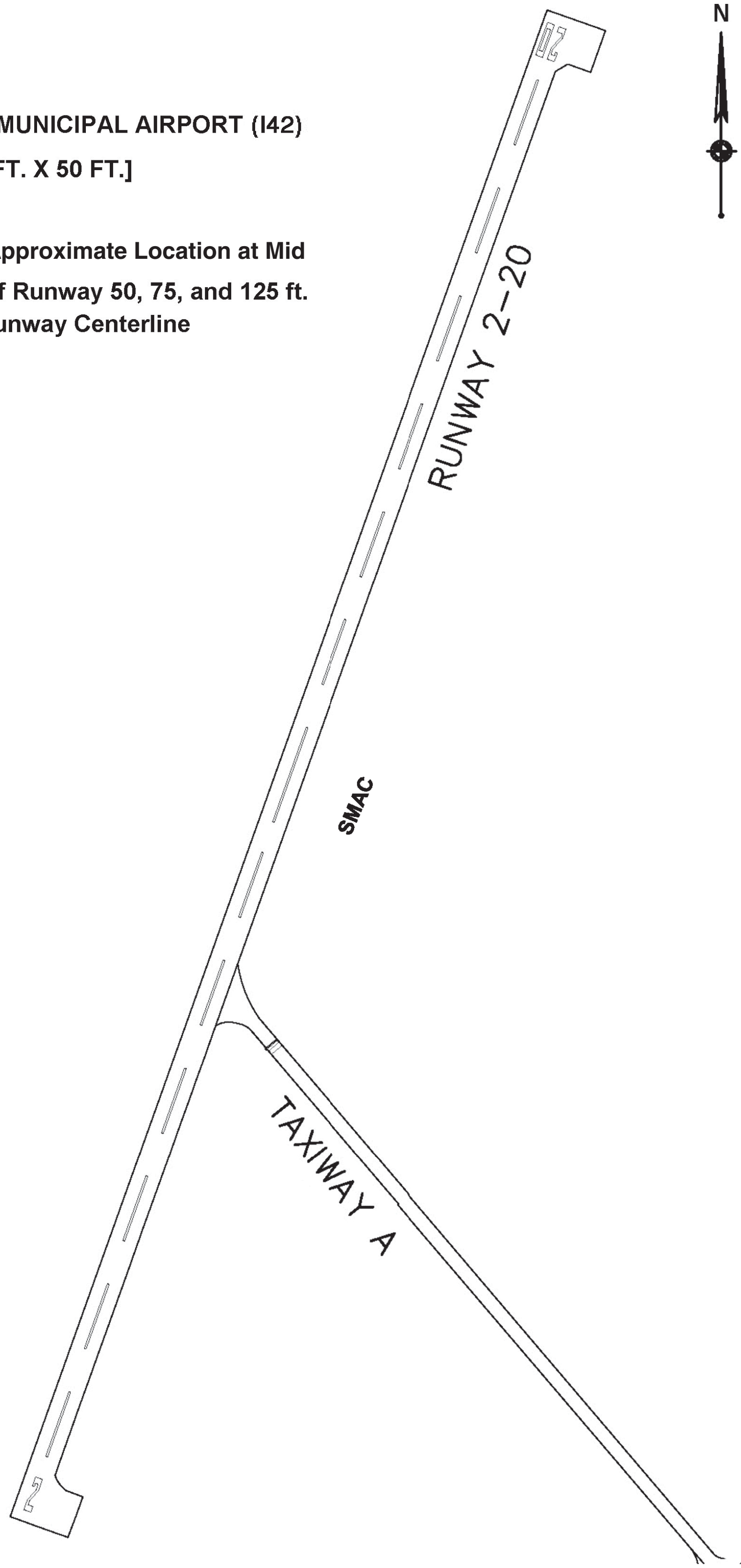


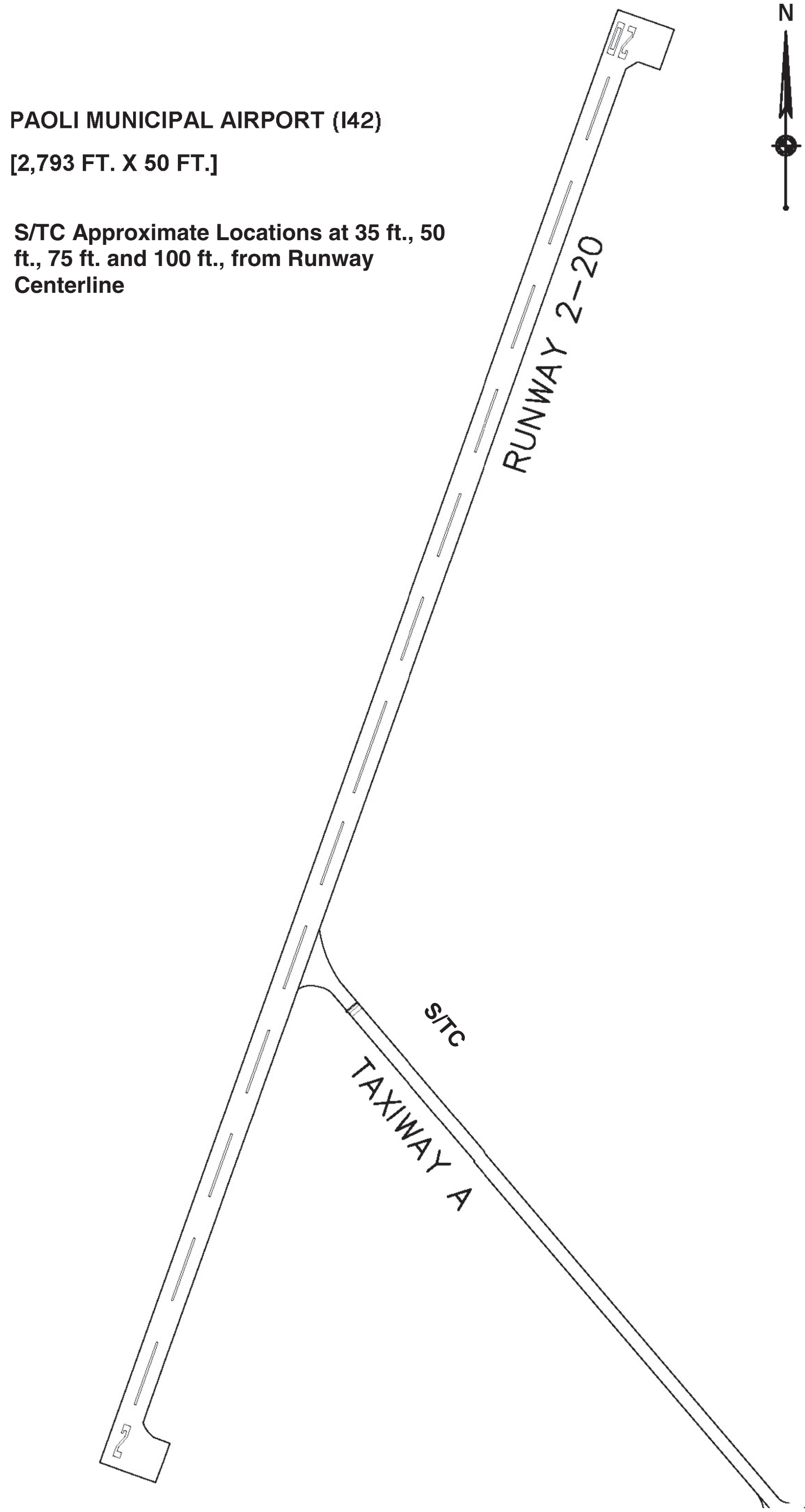

PAOLI MUNICIPAL AIRPORT (I42)
[2,793 FT. X 50 FT.]
AAC Approximate Locations at
Mid Point of Runway 50, 75, and 125 ft.
from Runway Centerline
RUNWAY 2–20
AAC
TAXIWAY A
N

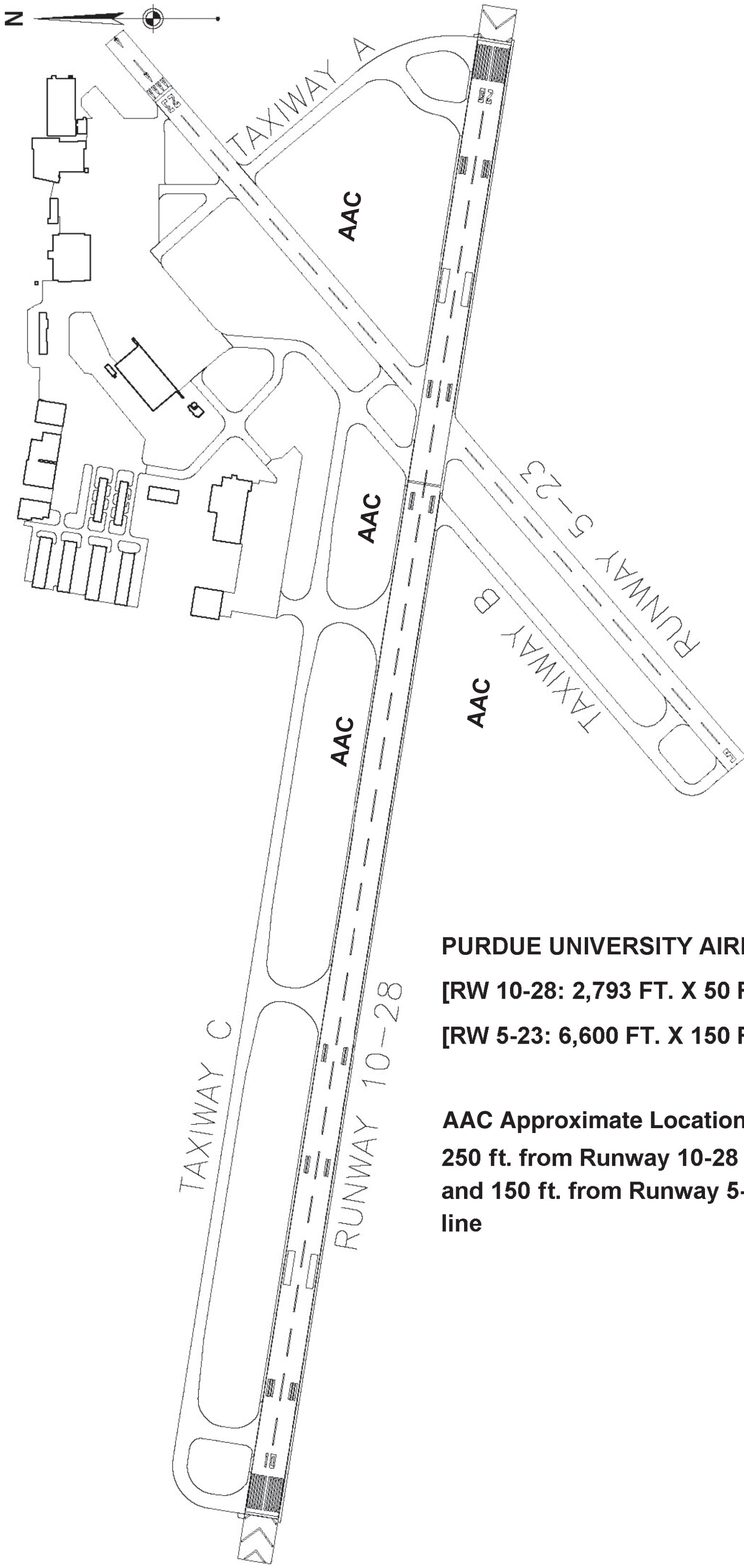
PAOLI MUNICIPAL AIRPORT (I42)

[2,793 FT. X 50 FT.]

SMAC Approximate Location at Mid Point of Runway 50, 75, and 125 ft. from Runway Centerline




PAOLI MUNICIPAL AIRPORT (I42)
[2,793 FT. X 50 FT.]
S/TC Approximate Locations at 35 ft., 50 ft., 75 ft. and 100 ft., from Runway Centerline
N
RUNWAY 2–20
20
2
S/TC
TAXIWAY A

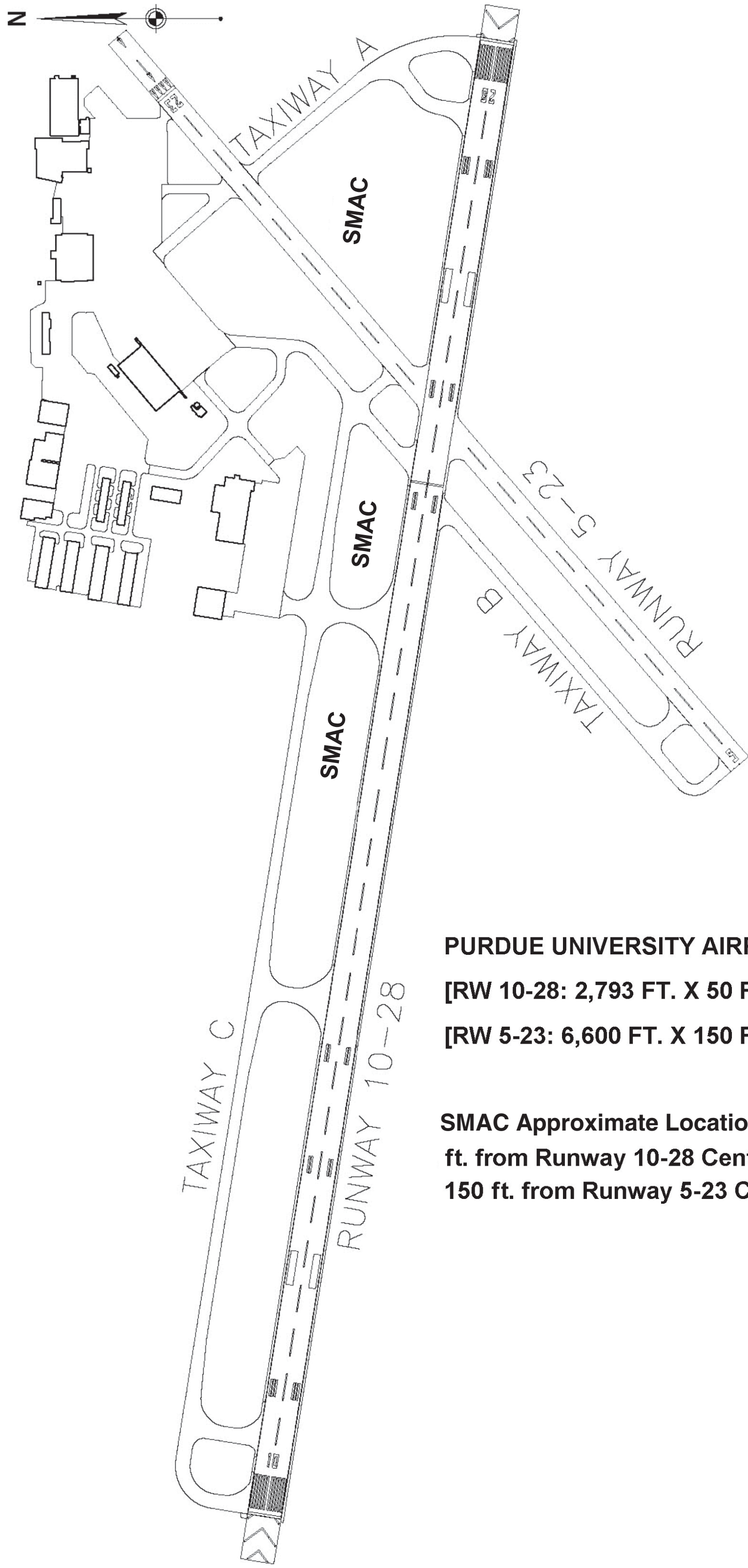


PURDUE UNIVERSITY AIRPORT (LAF)

[RW 10-28: 2,793 FT. X 50 FT.]

[RW 5-23: 6,600 FT. X 150 FT.]

AAC Approximate Locations at 250 ft. from Runway 10-28 Centerline and 150 ft. from Runway 5-23 Center-line



PURDUE UNIVERSITY AIRPORT (LAF)

[RW 10-28: 2,793 FT. X 50 FT.]

[RW 5-23: 6,600 FT. X 150 FT.]

SMAC Approximate Locations at 250 ft. from Runway 10-28 Centerline and 150 ft. from Runway 5-23 Centerline

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation