9-2009

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Recommended Citation

Robinson, D. D. (2009). *GIS for Airports – Electronic Terrain and Obstacle Data Model* (Master's thesis, University of Redlands). Retrieved from https://inspire.redlands.edu/gis_gradproj/135

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GIS for Airports – Electronic Terrain and Obstacle Data Model

A Major Individual Project submitted in partial satisfaction of the requirements
for the degree of Master of Science in Geographic Information Systems

by

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Douglas Flewelling, Ph.D., Committee Chair
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September 2009

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Acknowledgements

Accomplishing this project would have been impossible without the help and encouragement of many people. I must begin by acknowledging my dear partner, Allen Omoto, without whom none of this would have been possible. He persuaded me to take a chance on a new career path and pursue this MS GIS degree. He helped me with statistics, helped edit papers and PowerPoint presentations, and gently prodded me to get things done. He put up with chaos at home, and patiently listened to “I’ll get to it sometime” all year long. Thanks Allen, I promise this was all worthwhile! I would also like to thank the rest of my family, and all my friends, for holding me up throughout the year. How can people endure so much complaining?

I also want to thank my primary contact at ESRI, Shane Barrett, Aeronautical Solution Product Manager. Shane was instrumental in shaping the scope and extent of this project, proving to be very flexible and accommodating to changes along the way. He was very accessible throughout the project, even providing me an office in which to work at the ESRI campus. His patience and perseverance as I struggled with aeronautical data and SDE databases will forever be appreciated.

Next, I want to express my gratitude to my project committee: Ruijin Ma, Ph.D., and Douglas Flewelling, Ph.D. (Committee Chair). Thanks to Ruijin Ma, for his enthusiastic interest in my project early on, and his thoughtful comments and edits of this document. And a special thanks to my chair, Douglas Flewelling who kept me focused and on scope all along the way. His beneficial repetition of the mantra “…the best MIP is the completed MIP” single handedly is the reason this document was finished. With good humor and respect for my best judgment, he pressed me along to complete the project in time for my scheduled defense.

This program would not function without the steadfast support of the MS GIS staff and faculty. Thanks to the staff at the Research Institute and all our ESRI instructors. A special thanks to Debra Riley, Program Coordinator, for her special qualities of patience, organization, and friendship to all the frenzied students of Cohort 14.

A special thanks to due Dorothy Watkins, my friend in Cohort 14, whose help with Model Builder provided a breakthrough in creating a better selection process in my project.

And finally, it is with a sad heart that I say goodbye to my colleagues in Cohort 14. From a seemingly disparate group of individuals, we coalesced into a band of friends who championed one another through a year of struggles and triumphs. I dare say I will never again experience the kind of camaraderie and closeness we had with Cohort 14. I will cherish the times I spent with you in Lewis 104. Thanks for a very, very special year.

Abstract

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This project presents a custom GIS solution to aid in the production of electronic terrain and obstacle data sets (eTOD) for the world's airports. The eTOD mandates underlie the International Civil Aviation Organization's (ICAO) effort to modernize world air traffic control. ICAO has set a deadline of November, 2010 for nations to assemble eTOD sets for all their airports. The project client, ESRI, sought a custom eTOD solution for users, with limited GIS experience, to assess the quality of their terrain and obstacle data and plan for further data acquisition. A file geodatabase was developed to organize the user's existing aeronautical data and manage these data for project application use. The eTOD rules establish data quality standards for four Coverage Area designations, each represented by specifically shaped and sized boundaries around airports. Methods were developed to generate these boundaries using tools assembled with ArcGIS Model Builder in ArcView. The models simultaneously select the obstacles within the generated boundaries for data quality assessment. With limited training, a user can easily organize their data, automatically generate the eTOD Coverage Areas, and produce data quality assessment reports in support of their preliminary efforts towards reaching eTOD compliance.

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List of Acronyms and Definitions

ADHP	Aerodrome/Heliport
AIXM	Aeronautical Information Exchange Model
CAT II/III	Specific categories (CAT) of instrument landing capabilities at airports
eTOD	Electronic Terrain and Obstacle Data
ICAO	International Civil Aviation Authority
PLTS	Production Line Tool Set

Chapter 1 – Introduction

Aircraft fly safely around the world owing, in part, to the coordinated efforts of a global network of national air traffic control agencies. Central to this vital cooperation is the implementation of a common aeronautical language, an overriding set of rules and procedures to produce and distribute aeronautical information. These standards require, for example, an aeronautical chart for Nairobi, Kenya, to be formatted and distributed precisely as for a chart for Redlands, California. Surprisingly, aeronautical charts are still printed, and the data from which they are derived are often not in digital form. However, an international effort is underway to update the production and dispersal of this information as the standard in digital format. A first step in this transformation is to establish electronic terrain and obstacle data (eTOD) for all the world's airports.

This project proposes a prototype eTOD solution utilizing geographic information systems (GIS) to plan, organize, and create digital data sets of the terrain and obstacles associated with civilian airports around the world. Such data must be produced in accordance with strict criterion set by the International Civil Aviation Authority (ICAO), the lead agency coordinating global air traffic control. Obtaining and managing digital geospatial data, such as terrain and obstacle information, is a first step in ICAO's plan towards modernizing air traffic control (International Civil Aviation Organization, 2005a). ETOD mandates specify a comprehensive set of standards for collecting, modeling, utilizing and sharing electronic terrain and obstacle data. The ICAO set a deadline of November, 2010 for nations to produce and distribute eTOD (Pavlovic, 2008). The client for this project, the Environmental Systems Research Institute (ESRI), has identified potential clients, predominately smaller nations and agencies, who are looking for assistance in meeting this deadline. This project proposes a solution for addressing the specific tasks and challenges of executing the eTOD mandates in a custom GIS environment.

1.1 Client

The sponsor for this project, Environmental Systems Research Institute (ESRI), produces the well-known ArcGIS suite of GIS computer software and technologies. Their Professional Services Division offers industry specific solutions and support for a wide array of business interests, with the airport and aviation industry being a primary example. In support of this industry's particular needs, ESRI developed the PLTS (Production Line Tool Set) Aeronautical Solution, an ArcGIS extension optimized for managing aeronautical datasets and producing and updating aeronautical charts (Environmental Science Research Institute [ESRI], 2008). In addition to charting, airports employ ESRI products to help manage their complex facilities, from monitoring noise abatement, to modeling intricate three-dimensional airspace and approach patterns (ESRI, 2003). Their current and potential airport clients are now facing the challenges of producing eTOD datasets in the short time authorized by the ICAO. In response, ESRI's Aeronautical Solution team is busy developing custom eTOD solutions. As a complement to the team's efforts, this project presents a custom GIS solution to support the preliminary analysis and planning stages of eTOD implementation.

This project compliments ESRI's current eTOD offerings to provide clients essential tools and methods for addressing their eTOD execution challenges. In March 2009, ESRI published the Aeronautical Solution 9.3 Service Pack 1, which incorporated improved functionality for eTOD tasks, including upgrades for eTOD workflows and an eTOD compatible geodatabase schema (ESRI, 2009). This PLTS solution, however, is an expensive and complex software package requiring extensive training and expert knowledge of aeronautical data. ESRI recognizes the need for a simpler, less costly eTOD product designed specifically for the numerous smaller nations and agencies that lack the resources and skills to implement PLTS, but who still desire a process for initializing eTOD compliance. This project presents such a solution. In accordance with company objectives compiled by principal contact Shane Barrett, Aeronautical Solution Project Manager, this project puts forward tools and methodologies designed to function in ESRI's ArcView GIS software.

1.2 Problem Statement

As the lead agency charged with regulating global civil aviation, the ICAO has established ambitious goals towards modernizing the world's air traffic control system. As a primary aim, they have authorized the production of extensive sets of digital aeronautical data. A required subset, electronic terrain and obstacle data, must be submitted for all the world's civilian airports by November 2010. Many member states and agencies are struggling to meet this ambitious deadline, particularly due to the challenges of complying with the exacting standards set for data collection and organization. The costs associated with acquiring data for each airport are very high, and the expertise to create these data sets is lacking in many nations (Reid, 2008). ESRI recognizes that current and potential customers are looking for a system to aid in their efforts to meet these demanding directives.

In most cases, terrain and obstacle data correlated to individual airports have already been collected for aeronautical charting, but surprising amounts are not in digital form. And because of the stringent accuracy standards set by eTOD, existing digital data often does not conform. Potential customers need a process to evaluate their existing data and measure it against eTOD standards. Furthermore, they need a planning tool to assess the extent of additional or supplementary data to obtain. Adding to the complexity, an assortment of data sets must be generated for each airport corresponding to the outlines of four specific geographic Coverage Areas delineated by ICAO rules. These areas designate the obstacle area boundaries, from the most general – the entire territory, to the most focused – operations around specific runways. The applicable category defines the shape and size of the area, and assigns incrementally stringent rules for data collection, data accuracy, and format. ESRI customers need effective approaches to establish these areas, and methods to quickly and efficiently employ them as groundwork in planning for the inevitable work of collecting additional eTOD compliant data.

1.3 Proposed Solution

The fundamental purpose of this project is to offer ESRI's customers a first step planning vehicle for implementing the eTOD sanctions. In the following section, this purpose is illustrated by a discussion of the goals and objectives of the project. The extent and limits of the proposed solution are carefully delineated. Finally, the project methods are introduced, outlining the principal steps, tools and procedures developed to address the specific project functions requested by ESRI.

1.3.1 Goals and Objectives

ESRI acknowledges that clients have many options in choosing a technology platform for implementing eTOD, from user managed, open source GIS applications to comprehensive, consultant administered server database schemes. This project intended to accentuate ESRI's assertion that GIS provides a preferred platform to plan for, organize, and format the unique sets of aeronautical data called for by the eTOD authorization. A standard geographic information system inherently manages data formats mandated by eTOD: raster data representing terrain, vector data representing obstacles, attribute data, and precise database schemas. More specifically, ArcGIS products are able to process the aeronautical data formats dictated by the Aeronautical Information Exchange Model (AIXM) 5.1, a conceptual model adopted by eTOD as the global standard for the effective exchange of digital aeronautical data. On top of the intrinsic functionality of a standard GIS, ESRI's ArcGIS products allow specific tools and methods to be customized in order to optimize functionality and address the unique challenges of eTOD implementation.

ESRI's objectives in marketing an eTOD solution follow a two pronged approach. First, they appreciate that eTOD compliance is ultimately a continuous effort of repeated data collection, update and improvement. Their PLTS – Aeronautical Solution provides valuable tools and methods for such ongoing management of eTOD sets. Second, ESRI also realizes that many customers lack the adequate time, expertise, or resources necessary to employ the complex and costly PLTS-based eTOD solution. These customers need an economical, easy to implement system as a first step in planning their eTOD compliance strategy. They need to be able to easily construct the four area boundaries for each of their airports, assess the current state of their data within these boundaries, and plan and prioritize for additional data gathering. Offering an effective first step eTOD planning solution provides valuable opportunities for ESRI to expand their customer base, market their premium PLTS solutions, and establish enduring client relationships.

Underpinning ESRI's goal of proffering an eTOD planning product is the requirement that this project present an easy to use, low cost introduction to their family of aeronautical solutions. ESRI's products are offered in sequential license levels of increasing performance. Optional software extensions are also available which add further functionality, like geostatistics. This project was required to be built and function in ArcView, the lowest license level of the ArcGIS suite, without the aid of any extensions. ESRI preferred that the tools and methods employed be based on core ArcGIS functions, but the development of custom tools or programs was acceptable if it enhanced ease-of-use. The project had to be designed to best serve ESRI's intended clients, agencies and nations with limited technical and financial resources who desire systems where minimal training and hardware/software investment are required. With this in mind, the project was designed to facilitate an easy, step-by-step process to establish the four areas, assess existing data, and plan for subsequent data acquisition.

1.3.2 Scope

The extent of the completed project was determined primarily by ESRI's explicit goals for an introductory eTOD solution. Ultimate project success rests on the utility of the project components, specifically their capacity to provide a useful framework for tackling the initial stages of eTOD compliance. All of the tools and procedures created are accessed in ESRI's ArcCatalog and ArcMap interfaces within the lowest license level of ArcGIS. The project process produced a variety of deliverables to ESRI, from the eTOD geodatabase schema to area delineation models and tools. This was accomplished by the successful completion of the following tasks.

First, a file geodatabase was developed and tested to organize and format the extensive set of data from which the final eTOD set would be extracted. Because of the size of the data set, the file type geodatabase was used due to its capability to store such large datasets. The ICAO rules and standards were addressed in the architecture of this geodatabase, from accommodating the required features (e.g. point, line and polygon features) to supporting the data interchange formats. A file of the completed geodatabase schema and a geodatabase diagram represented the first set of deliverables for the project.

Second, tools were developed to generate the four Coverage Area delineations required for each airport. As previously noted, the four areas represent increasingly focused geographic extents. Data for each area must comply with stringent standards of quality as dictated by the specifics of the designation. To generate each of the unique Coverage Area shapes, a careful sequence of tools was established using ESRI's Model Builder technology. Model Builder is a system interface used to automate workflows and functions in order to execute tasks repeatedly. The methods and tools were carefully chosen to optimize simplicity and ease-of-use for the client.

Third, techniques were developed to assess existing data in comparison to the eTOD area standards, and plan for further data acquisition. At the end of the Coverage Area delineation models, steps were added to isolate the appropriate obstacles within their respective Coverage Areas. With these obstacles automatically selected, the user can print out the attribute table of the chosen obstacles and compare fields that record data quality with the eTOD quality standards for the accompanying Coverage Area. Superimposing the Coverage Area boundary on contextual data, like land form or political boundary features, help in the estimation of work effort to acquire additional data.

1.3.3 Methods

To accomplish this project, a sequence of procedures was followed as outlined below. The completed workflow can be summarized by a series of fundamental steps. These include: data gathering, creating the eTOD geodatabase, and developing tools to create the four Coverage Area delineations.

The initial step was assembling data for the project. The client, ESRI, provided the majority of the aeronautical data. PLTS - Aeronautical Solution tutorial data was used as a test case scenario for a prototypical eTOD application. This data set included a wide range of aeronautical information for the state of California, from outlines of airspace to runway and taxiway layouts. The set focused on the Salinas Municipal Airport, which was utilized as an example airport for which to build the four area delineation tools. An important update to this data set was later provided that included the new point, line, and polygon obstacle features as required by the eTOD rules. Aerial photographs and cultural features for the area surrounding Salinas, CA, were obtained to provide contextual information for the generated obstacle areas, in order to help guide the data acquisition planning.

With the representative data collected, a geodatabase was designed to organize existing client data and set up a preliminary schema for the eventual terrain and obstacle sets. A new file geodatabase for the eTOD data was created by editing the existing SDE database provided with the PLTS tutorial data set. Once the original geodatabase had been cut back to the principal eTOD features, the new obstacle area feature class, and line, polygon and point obstacle feature classes had to be added with their respective aeronautical information attributes. In addition, the eTOD guidelines and the newest AIXM 5.1 schema were carefully examined to determine if any additional features or relationships needed to be added to the final prototype eTOD geodatabase.

With the completed geodatabase loaded with the assembled data, methods needed to be developed to differentiate the data into the four eTOD Coverage Area delineations. Standard ArcView tools were utilized to build the representative area boundaries. These tools were assembled in a logical sequence using the Model Builder technology. Developing custom models for each area provided the user a set of simple steps to recreate the appropriate area boundaries for each airport**.** Care was given to minimize necessary input from the user, reinforcing the goal of providing a system for beginner GIS users.

The specific geometry of each eTOD area required the creation of five unique models. Per the ICAO mandate, the eTOD Coverage Areas are defined as (Figure 1.1): Area 1 – the entire state or territory; Area 2 – airport terminal control; Area 3 – airport/heliport area; and Area 4 – Category II & III operations areas (International Civil Aviation Organization [ICAO], 2007a). A data set corresponding to each area must be generated for every civilian airport under the client's jurisdiction. In some cases, Area 4 will not be applicable, as this represents airports with specialized instrument approach procedures. The Area 1 model simply selects the appropriate political boundary for the entire jurisdictional area, such as a country boundary, and reproduces it as a new Area 1 Obstacle area feature. Area 2 is differentiated by two models. In many large airports, a complex boundary around the airport is assigned as a terminal control area, a volume of controlled airspace for that airport's operations. The first Area 2 model selects this boundary, subtracts any restricted airspace, and merges this new boundary into an Area 2 obstacle area feature. If the selected airport does not have a terminal control area, a second Area 2 model creates a 45km buffer around the airport and subtracts restricted airspace as noted above. The Area 3 model utilizes runway and taxiway polygons to create varying length buffers around these features. These buffers are merged into a new area 3 Obstacle area feature. And finally, the Area 4 model creates a 900 x 120 meter rectangle at the end of each runway threshold. Details on the specific parameters, required user inputs, and tools used for each model will be further discussed in Chapter 5 – Implementation.

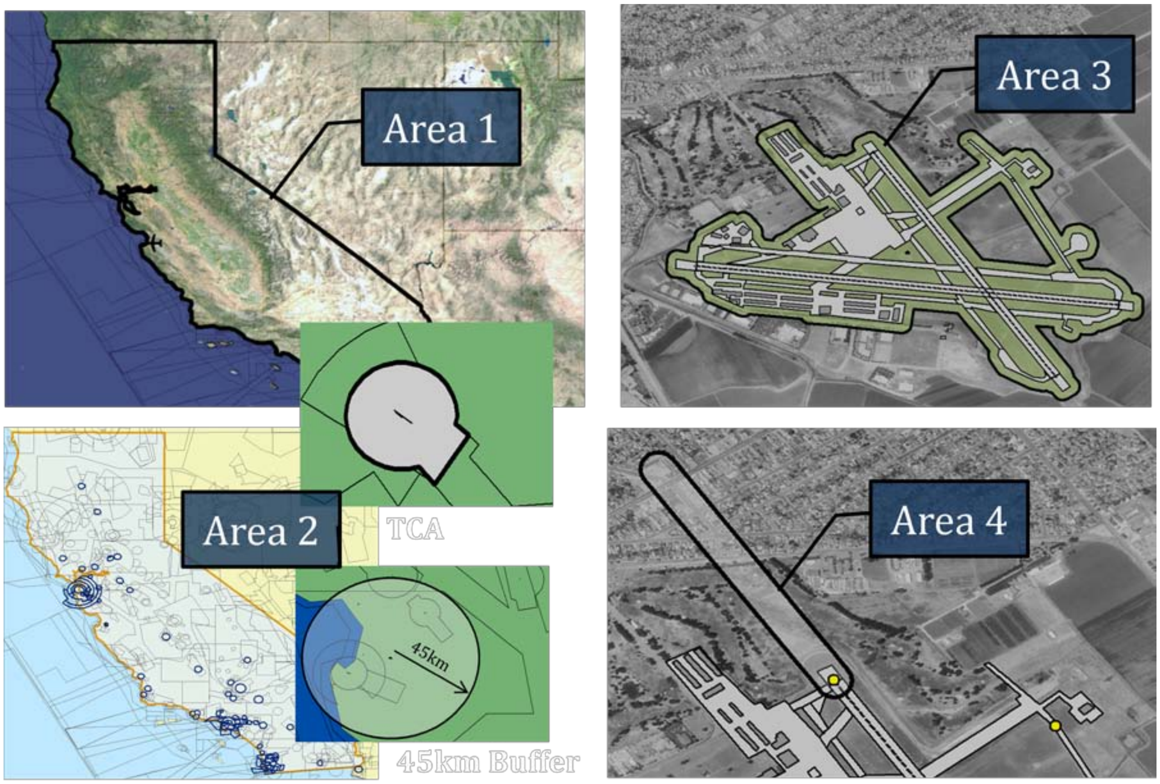


Figure 1.1: eTOD Coverage Areas

Generating the four area delineations is critical, as their establishment allows clients to appraise the adequacy of their existing data and determine the extent of additional data collection. In nearly all cases, agencies will have to carefully plan for new surveying of airport obstacles in accordance with the eTOD standards. For example, obstacles within Area 2 must be surveyed at horizontal accuracy of 5.0 meters, while Area 3 calls for 0.5 meter horizontal accuracy. Generating this new digital data is the biggest obstacle for meeting the 2010 deadline.

1.4 Audience

This report has been written with an intended audience in mind. A characteristic reader of this report would be an information manager for a national aviation authority who is looking for solutions to help plan for eTOD compliance. Or the reader may be a consultant hired to implement the eTOD mandates who is also looking for tools to help them accomplish their task. It can be assumed that in both cases, the reader has a professional understanding of the current state of aeronautical data and its terminology. They may not be completely familiar with the eTOD requirements, but once introduced, can recognize the challenges of working with their current data in relation to these mandates. As they are evaluating various GIS solutions, they have a general understanding of basic GIS principals and methodologies, but may not be as familiar with some of the more advanced techniques and tools. It is the intention of this report to sufficiently describe the objectives and design of the system in a vocabulary understandable to the intended audience.

1.5 Overview of the Rest of this Report

In the remaining chapters, discussions will concentrate on specifics, from a detailed description of system design to recommendations for future work. Chapter 2 sets the stage for the project – what is the context for this project and how does it fit into the efforts for modernizing air traffic control? Relevant literature will be cited to clarify the background for this project. In Chapter 3, the system analysis and design are presented. Here the major components of the system are presented and described as appropriate responses to ESRI's problem. The initial project plan is presented and analyzed in respect to the final outcomes of the project. Following these three initial chapters which outline planning for the project, the remaining chapters present what was actually accomplished.

Starting with Chapter 4, discussions concentrate on the execution of the project. Design of the geodatabases is presented in Chapter 4, from elements of the conceptual design to the loading of the data. Chapter 5 describes the actual implementation of the project. How were the models and tools created and how are they employed to best satisfy the goals and objectives of the project. Chapter 6 describes the successes and failures of deploying these models and tools. Were the reports and resultant information useful to the client? Chapter 7 summarizes the key points of this project report and presents recommendations for future work to expand upon or improve the results of this work.

Chapter 2 – Background and Literature Review

The establishment of electronic terrain and obstacle data sets for all airports is but a small step in the transformation of the worldwide air traffic control system. In this chapter, the objectives of this project are substantiated by outlining these global efforts to revolutionize aviation navigation and traffic management. Due to the technical limitations of the technologies currently employed, and the constraint of incrementally rising traffic levels, the current system no longer meets the demands of 21st century aviation.

In the following sections, a discussion of the future of air traffic control sets the context for the specific role of the eTOD mandates. The first section summarizes problems of the current outmoded system and leads to a description of a new model of managing global air traffic. Responsibility for developing this new paradigm rests with the International Civil Aviation Organization (ICAO). The next section introduces the founding of ICAO and how its initial mandate remains current through initiatives like the eTOD directives. ETOD represents one phase in the overall switch to digitally formatting, organizing, and transmitting aeronautical data. In the subsequent section, the traditional utilization of aeronautical data is contrasted with the use of digital data. And finally, descriptions of digital data models lead to a review of utilizing these data in GIS applications for aviation.

2.1 Management – The Future of Air Traffic Control

It may be surprising to realize that current air traffic control systems operate primarily with technologies dating back to World War II. To this day, flights across the globe are directed through vocal instructions to pilots over radio, and kept under surveillance by ground based-radar systems. The technical limitations of these aging technologies have greatly hampered improvements to aviation safety and efficiency. As new technologies like Global Navigation Satellite Systems (GNSS) have emerged, the aviation community has been quick to recognize the benefits of adopting these systems. But assimilating these new technologies into a global, interconnected network requires the herculean task of establishing common standards while soliciting worldwide cooperation and acceptance. Despite these hurdles, efforts are underway to completely overhaul the existing system, harnessing the significant advantages of satellite/computer based communications and surveillance. Revitalizing air traffic control is imperative, as the current system has nearly reached its ability to handle current traffic loads.

2.1.1 Problems of current air traffic control system

Existing air traffic control systems are no longer capable of managing the challenges of 21st century aviation. Air traffic has grown exponentially since the advent of current systems, and is expected to increase substantially in the future. According to ICAO estimates, commercial aviation will contend with 11 billion passengers by 2027; more than double the number in 2009, representing a 4.2 per cent annual increase (ICAO, 2008). The current system can barely handle current traffic, resulting in ever mounting delays. In the US alone, delays in just one year (2007) cost the economy $40 billion, according to a US Congress Joint Economic Committee report. During the same period, 740 million gallons of jet fuel were wasted due to these delays (Joint Economic Committee, 2008). Delays exacerbate the environmental impacts of flight. A study by the Intergovernmental Panel on Climate Change reported that aviation activities contribute to 3.5 percent of the human-derived sources of emissions affecting global warming, expected to rise to 5 percent by 2050 (Intergovernmental Panel on Climate Change, 1999). In addition, the current system constrains crucial advances in aviation security and safety (Federal Aviation Administration [FAA], 2008). These mounting problems call for an overhaul of the existing air traffic system.

The technical limitations of existing systems hinder any improvements to air traffic management. Aircraft are currently routed on predetermined zigzag paths determined by the location and range of ground-based radar surveillance and voice communication. In comparison to straight line routes, or altered courses optimized for weather or traffic conditions, segmented flight paths exacerbate inefficiencies. Meandering routes lengthen flight duration, escalating noise and air pollution. The preset nature of these paths deters flexible rerouting informed by real time conditions, compounding weather and traffic delays. Moreover, existing technologies impede capacity growth, holding up improvements to accommodate ever increasing traffic. Because it takes radar 10 seconds to fix on aircraft, flights are spaced by miles for safety. In addition, aircraft must be separated vertically by a minimum of1000 feet, and take offs and landings must be ineffectively spread out. The current system has reached its capacity. A new paradigm of air traffic control must emerge to address these limitations.

2.1.2 Air Traffic Management

A global initiative is underway to transform air traffic control into a modern, digital, computer-based system. ICAO has termed this CNS/ATM- Communications, Navigation and Surveillance Systems for Air Traffic Management (ICAO, 2005b). This rather unwieldy acronym accentuates two important details of the transformation. First, the new system is being built upon a foundation of modern CNS technologies, supplanting voice and radar operations. Second, the new system – air traffic management – replaces the old model of air traffic control. This semantic shift intentionally contrasts the limitations of the outdated systems with the advantages of the new and improved system. Control aptly describes a rigid system of defined air routes, strictly delimited aircraft spacing, and restricted alternative routing in the face of real time weather or traffic interference. In contrast, management symbolizes a new paradigm of flexibility, with more straight line routing, and the potential to exploit real time data to reroute traffic to optimal configurations. This new paradigm is possible only because of significant advances in communications and surveillance technologies.

An interrelated set of advanced technologies will power modern air traffic management systems. Data link communications, a system of digital data transmission, will replace voice communications. Current methods of aeronautical data assembly and formatting, such as paper aeronautical charts, will be accordingly transformed into digital aeronautical information services (AIS). Navigation and surveillance will utilize the Global Navigational Satellite System (GNSS), enhancing the ability of aircraft to communicate their positions to ground stations and nearby aircraft through a system called automatic dependent surveillance broadcast (ADS-B) (ICAO, 1997). Integrating these systems into a comprehensive air traffic management scheme offers significant improvements to worldwide aviation operations.

A shift to air traffic management will usher in considerable enhancements to aviation safety and efficiency. The transformation to digital communication and satellite navigation will allow aircraft to fly in a “single sky.” Because of satellite’s global reach, airspace will no longer be segmented into control center sectors delimited by radio and radar signal strength (Brochard, 2007). Vast areas previously unavailable for flight will be opened up. In many developing countries, and within vast isolated areas, constructing expensive ground based navigation aids is impractical. Satellite communication offers a more cost-effective solution to providing navigation in these formerly out of bounds areas (International Air Transport Association [IATA], 2003).

Air traffic management will signal an era of flexibility and optimized flight operations. Supported by new digital tools, pilots will work with air traffic control to determine the shortest and most direct routing for their flights. Digital communication and satellite navigation will lessen the probability of costly errors and facilitate shorter flight times, thus reducing delays, saving money, and lessening environmental effects (IATA, 2003). The United Nations’ Intergovernmental Panel for Climate Change (IPCC) acknowledged these potential advantages in their Special Report on Aviation and the Global Atmosphere. It maintains that the worldwide implementation of a CNS/ATM system, like the one endorsed by ICAO, has the potential to save the aviation industry and customers 4.3 to 6 billion dollars per year, and reduce carbon dioxide (CO2) emissions by 20 million tons through a 6-12% improvement in fuel efficiency (IATA, 2003). From increased efficiency to enhancements in aviation safety, air traffic management will substantially advance global air traffic control.

The technologies to upgrade air traffic control are now readily available. Implementing these technologies, however, requires a highly complex global effort to establish and agree upon interoperable standards and protocols. Industries and governments must work together, global objectives must come before regional demands, and national airspace borders must be eliminated. All these challenges, and more, confront ICAO’s efforts to launch a new system. As far back as 1987, Duane W. Freer, former director of ICAO’s Air Navigation Bureau, recognized that ICAO’s biggest challenge would be executing CNS/ATM, claiming its implementation would measure ICAO’s future relevance (Freer, 1987).

2.2 A Mandate for Change

Since ICAO’s inception in 1944, navigation, surveillance, and air traffic control technologies have profoundly influenced their standards and practices. Because of the difficulties in implementing new technologies worldwide, ICAO has been slow to introduce new traffic control methodologies. However, foreseeing the significant system improvements to be gained by assimilating new technologies, like satellite-based surveillance, ICAO introduced a Strategic Action Plan in 1997. The plan was instigated to reinvigorate the goals of the original founders in light of 21st century aviation considerations (ICAO, 2005b). The primary objective of this plan was to establish a seamless global navigation structure – the Global Air Traffic Management System (ATM).

2.2.1 International Civil Aviation Organization

The authority to instigate system overhaul stems from ICAO's directive to set the standards for worldwide civil aviation traffic control and planning. ICAO, headquartered in Montreal, Canada, was founded in 1944 as an agency of the United Nations (ICAO, 2005b). Its powers are derived by a treaty which to date has been ratified by 188 countries (including the United States), "…making it one of the world's most widely accepted international legal instruments" (ICAO, 2005b, p. 6). Through a set of "strategic objectives," ICAO strives to "…achieve its vision of safe, secure and sustainable development of civil aviation through cooperation amongst its member states" (ICAO, 1997, p. 1). These global objectives include: improving safety, ensuring aviation security, advancing measures to protect the environment, increasing the efficiency of aviation procedures, sustaining an uninterrupted flow of aviation operations, and bolstering international aviation law. The remarkable safety and reliability of international air travel over the last 60 years owes much to the successful fulfillment of these objectives. But with the ever increasing growth of international air travel, the unique challenges of 21st century aviation compel ICAO to continually revaluate its purpose and relevancy.

ICAO's Strategic Action Plan calls on member states to design and implement new CNS/ATM systems. These independent systems must be completely interoperable and integrate seamlessly within a global network, and comply with the strict models and standards set forth by the plan (ICAO, 2005a). ICAO has developed protocols and procedures for producing and sharing digital aeronautical data that will be the foundation of a homogenous, worldwide computer-based air traffic management system. The first of these protocols to be codified are the electronic terrain and obstacle data initiatives.

2.2.2 Instituting electronic terrain and obstacle data

The establishment of comprehensive electronic terrain and obstacle databases is a keystone of ICAO's plan to direct international civil aviation in the 21st century. The detailed eTOD directives were enacted in 2004 as Amendment 33 to Annex 15 of the ICAO convention, which outlines the tasks and responsibilities of aeronautical information services (AIS). The mission of these services is to "…ensure the flow of information necessary for the safety, regularity and efficiency of international air navigation" (ICAO, 2007a, p. 27). Chapter 10 of Amendment 33 further defines the formatting of terrain and obstacle data (ICAO, 2009). Such detail is underscores ICAO's principal purpose:

> Air navigation safety is the ICAO highest priority and to ensure the availability of data of required quality, ICAO specified that each State must take all necessary measures to introduce a properly organized quality system and implement quality management. (IATA, 2003, p. 14)

But among the abundant types of aeronautical data, why has ICAO concentrated on terrain and obstacle data as a first priority?

ICAO has deliberately chosen terrain and obstacles as the first aeronautical data to be required in digital form. Terrain collisions remain the number one type of aircraft accident (IATA, 2003)**.** ETOD priorities reinforce ICAO's assertion that "...significant flight safety improvements could be achieved by in-flight and ground-based applications that use quality electronic terrain information**”** (IATA, 2003, p. 17). Paragraph 10.1 of the eTOD amendments specifically lists such applications , like a “...ground proximity warning system with forward looking terrain avoidance function and minimum safe altitude warning (MSAW) system” (ICAO, 2007a, p. 76). These warning systems use electronic terrain and obstacle data to enhance a pilot’s awareness of surrounding situations. Many more valuable applications utilize these data, such as advanced cockpit navigational displays, airport taxiing maneuver displays, runway incursion prevention technologies, and flight simulation (ICAO, 2007a). These systems all rely on precise, dependable, and timely data developed using precise interchange formats to facilitate data sharing. Implementing such data is the fundamental role of the eTOD mandates.

ICAO has established optimistic goals and specific deadlines for executing the eTOD directives. The mandates introduce demanding standards for the acquisition of terrain and obstacle data, the organization of databases, and the distribution and maintenance of these data (Pavlovic, 2007). Each member state or agency is responsible for producing multiple eTOD sets within precisely defined areas delineations for all types of airports, private and public, under its jurisdiction. They are further responsible for guaranteeing ICAO quality standards for every data set. Exacerbating this hardship is the fact that all data sets must be complete by November 19, 2010. Clearly, ICAO is very serious about moving ahead aggressively with its overhaul of international air traffic control.

2.3 Aviation Data

Pilots depend on the accuracy and timeliness of copious amounts of aeronautical information. Published aeronautical charts illustrate a wide range of information, from air navigation routes and airport layouts, to the location of restricted airspace. Traditionally, these data have been manually compiled, symbolized, drafted, and distributed on paper charts and maps. Seeing a flimsy chart clipped to the control column of a modern jetliner is common. But efforts are underway to modernize the organization and dissemination of aeronautical data.

Just as air traffic control is being transformed into air traffic management, aeronautical information service traditions are being replaced with aeronautical information management protocols. The ICAO convention clearly describes the “vital role” of aeronautical information services (AIS):

> Annex 15 defines how an aeronautical information service shall receive and/or originate, collate or assemble, edit, format, publish/store and distribute specified aeronautical information/data. The goal is to satisfy the need for uniformity and consistency in the provision of aeronautical information/data that is required for the operational use by international civil aviation (ICAO, 2005a, p. 1).

This uniformity and consistency is enforced in the issuing of Aeronautical Information Publications (AIP), the standardized vehicles for disseminating aeronautical information. AIP’s remain up to date through the publication of amendments and supplements, key to which are NOTAMS (Notice to Airmen), announcements to pilots of en route hazards (Graham et al., 2005). This problematic process of distribution and subsequent update will be simplified and improved by implementing a digital data model. In fact, all of the key functions of AIS, from originating to distributing aeronautical data, will be greatly enhanced by the adoption of digital aeronautical data.

2.3.1 Digital Aeronautical Data

The use of shared digital aeronautical data will underpin the operation of a homogenous, worldwide, computer-based air traffic management system. Users of the traffic control system, including the International Air Transport Association (IATA), are imploring ICAO to establish common standards for this new digital paradigm:

> There is an urgent requirement for a "single global scenario" for future aeronautical communications infrastructure to be coordinated by ICAO in order to prevent the proliferation of local and regional solutions (IATA, 2003, p. 3).

ICAO did anticipate the eventual use of digital databases when they adopted WGS-84 as the standard geodetic reference system for international aviation (ICAO, 2007b). ICAO foresees the establishment of computerized aeronautical information services (CAIS) built on a common architecture of database, server, and client technologies, eventually leading to a world wide web service, the aeronautical information database (AID) (ICAO, 2005b). But a common format for data exchange must first be adopted.

2.3.2 Aeronautical Data Exchange

A primary objective of promoting digital data sources is facilitating the rapid and easy dissemination of these data. Automatically transferring real time data digitally is fundamental to transforming a paper-based model of aeronautical information systems into modern, computer-based aeronautical information management systems (Brunk, 2008). This worldwide sharing of data is possible only if these data are produced in the same “language” (Brunk et al., 2004). Brett Brunk, FAA’s Program Manager for Digital AIM, reiterates, “...aviation needs an interoperable language for aeronautical information that can be the foundation for modernizing AIS” (Brunk, 2008, p. 4). ICAO has the historic authorization to set standards for data interoperability under the auspices of SARPS – Standards and Recommended Practices (Pavlovic, 2008). In this capacity, ICAO has adopted the Aeronautical Information Exchange Model (AIXM). AIXM, an exchange model developed jointly by the FAA and Eurocontrol, was devised to facilitate the distribution of aeronautical information in digital format and is now the recognized standard for formatting aeronautical data. This format is constantly being revised, with the latest version, AIXM 5.1 soon to be published.

Several features of AIXM bolster its endorsement by ICAO. It conforms to ISO 19100 standards mandated by ICAO. It harnesses the benefits of a unified modeling language (UML), a “…visual language for capturing relationships, behavior and high-level ideas” (Brunk, 2007, p. 11). AIXM 5.0 introduced the use of Geography Markup Language (GML), an ISO exchange format developed by the Open Geospatial Consortium for encoding geographical features (Brunk et al., 2005). AIXM functionality facilitates the use of aeronautical data by many different applications, for many varied uses.

The newest version of AIXM addresses two important aspects of eTOD directives. The AIXM model integrates concepts of time. Its schema relates features to their time extent (for example, their permanence) (Brunk, 2007). This powerful functionality supports a key aspect of eTOD mandates, maintaining the timeliness of aeronautical data. Second, obstacle data must be represented in its most optimal form – point, line, or polygon data. For example, power lines are best represented by lines. Previous versions of AIXM only supported point features, but the newest version allows for the use of all types of vector data (Pal, 2008). Any eTOD GIS solution must be built upon the AIXM schema.

2.4 GIS & Aviation

Geographic information systems (GIS) provide valuable tools to address many challenges of modern aviation. A special report by Airport-Technology.com, a website dedicated to technological innovations for airports, succinctly outlines the range of GIS applications for aviation concerns (SPG Media, 2006). Commercial airlines utilize GIS to plan flight routing and track real time operations. Complex airspace configurations are modeled using GIS three-dimensional analysis methodology (SPG Media, 2006). The production of aeronautical charts is automated by utilizing managed digital databases, a key function of ESRI's PLTS (Production Line Tool Set) – Aeronautical Solution. GIS helps manage airports which are often encumbered by competing and overlapping safety, security, budgetary, and efficiency concerns. The spatial ramifications of these opposing issues can be safely modeled and tested in a GIS. Planners use GIS to analyze neighboring land use restraints, design noise pollution abatement mitigations, and study airport access and transportation alternatives. The maintenance of critical airport components, like runways and utility infrastructures, is aided by employing the functions of an airport GIS. Two examples of specific aviation GIS solutions illustrate their usefulness in addressing challenges unique to modern aviation: managing airport inspections, and flight hazard management.

One of the key responsibilities of airport operators is supporting safe operations like take offs and landings. To ensure this safety, airport managers coordinate daily facility inspections. Neubert Aero Corporation, a Florida-based supplier of airport safety products, provides customized GIS technologies for daily airfield data collection. Their Integrated Airfield Self-Inspection and Reporting Solution (*i*-AIR) is a GIS/GPS map technology designed to facilitate the management of these daily field checks. It works to streamline the process of inspection, from the reporting of airport irregularities (like pavement cracks) to the automation of repair work orders. It has been employed at locations like the Louisville International Airport to "…improve operational efficiency, decision making, and problem solving" (Neubert Aero Corporation [NAC], 2007). ***I***-Air is an excellent example of how a GIS organizes and maintains sets of complex data, transforming them into useful information. The following description illustrates the profound import of generating timely information.

On a cold day in New York City, January 16, 2009, a US Airways airliner lost power in both engines after colliding with a flock of Canada geese. While the pilots made an historic and safe crash landing in the Hudson River, their story highlights the multitude of risks faced during flight. The United States Air Force, in cooperation with the FAA, has developed the United States Avian Hazard Advisory System (USAHAS), a program that aims to provide "…the best available geospatial bird data to reduce the risk of bird collisions with aircraft" (United States Air Force, 2009). Their website offers a GISpowered application that estimates the risk of such collisions at a user defined date, time, and location. The GIS analyzes habitat, migration patterns, species characteristics, and location information and maps the resultant hazards. In every application of a GIS, generating useful information requires the collection of quality data. The rigors of eTOD implementation arise out of the necessity to provide the highest quality terrain and obstacle data.

2.5 Summary

The previous sections outlined the intentions and objectives of realizing the eTOD initiatives in the context of modernizing air traffic control. The International Civil Aviation Organization has set in motion its mandate to make fundamental changes, of which the eTOD initiatives are an integral part. But the directives of eTOD do not state what specific methodologies must be used to create the required data sets. Rather, they set the rules and standards for the data and leave the means of meeting these standards to the responsible parties. The next section outlines how the design of this project addressed the needs of potential clients to meet the requirements of the eTOD mandates.

Chapter 3 – Systems Analysis and Design

The client for this project, Environmental Systems Research Institute (ESRI), recognizes a great opportunity to assist potential users in complying with the eTOD regulations. This section expounds on their original intentions and objectives for providing, through this project, a long-awaited eTOD solution designed specifically for the needs of these anticipated clients. A succinct statement of the essential problem to be solved by this project is first presented. From this strategic starting point, the specific requirements of the project are formulated. This section will explain what the system should do and in what manner it should perform. How this will be implemented is described in the discussion of the system design. And finally, the original plan devised for successfully completing the project is introduced.

3.1 Problem Statement

Nations and agencies with limited financial and technical resources need a user-friendly, simplified eTOD GIS solution that can be utilized in-house by agency staff, circumventing the need for costly, time-consuming consultant services. Such a solution would provide a valuable framework to assist in the required collection and organization of eTOD data sets. Most nations and agencies already require airports to collect data on surrounding terrain and obstacles, but many of these data have not been collected with accuracies matching or exceeding eTOD requirements and many are not in digital form. Potential customers need a process to evaluate their existing data and measure them against eTOD standards. They also need a planning tool to assess the extent of additional or supplementary data needed. GIS technologies provide useful tools to produce, organize, and analyze these required datasets.

The International Civil Aviation Organization has mandated that member states produce electronic terrain and obstacle data (eTOD) sets by November 18, 2010. This is an enormous undertaking, and responsible parties are struggling to meet these demanding deadlines. Adding to the complexity, an assortment of data sets must be generated for each airport corresponding to the specifications of four specific geographic Coverage Areas. ESRI customers need effective approaches to establish these areas, and methods to quickly and efficiently employ them as groundwork in planning for the expected work of collecting additional eTOD compliant data. ESRI recognizes that current and potential customers are looking for a system to aid in their efforts to meet these demanding directives. As such, they have identified specific requirements preferred in such a system.

3.2 Requirements Analysis

ESRI has determined that many smaller nations and agencies need an easy-to-use, low cost solution to address eTOD compliance. The first step toward compliance is acquiring the required terrain and obstacle data, with the ultimate goal of producing accurately formatted and complete eTOD datasets for each and every airport. The responsibility for producing these sets rests with the prototypical project client, a client with minimum technical skills who desires a system that can be implemented quickly with minimal hardware/software requirements and training. Simplicity, relative low costs, and producing the minimum standards of eTOD are the hallmarks of the project requirements.

An analysis of the specific requirements of this eTOD project can be categorized as such: functional requirements, and non-functional requirements (operational, technical, and transitional). Functional requirements are generated from specific user needs and describe what information or answers the system should provide. For example, a primary requirement of this project is to generate the four eTOD area delineations. The ease of generating these areas, however, is an example of a non-functional requirement. Non-functional requirements specify in what manner the system should perform. Should the project be designed for users with minimal GIS experience? Should the project utilize a specific version of software? In addition to these operational and technical concerns, non-functional requirements also include how the client will transition into implementing the system. Transitional requirements center on the seamless employment of the system, from proper data gathering, to thorough testing and prototyping of the solution. The following sections describe in detail the specific functional and non-functional requirements of this project.

3.2.1 Functional Requirements

Clients for this project already work with aeronautical data and information. But in most cases, working with digital data and complying with the exactitudes of eTOD rules is a new challenge. These clients need a system to manage this new type of spatial data, visualize it, and transform it into useful information. The primary function of this project is to provide tools and methods to initiate eTOD compliance. Producing complete and final eTOD sets for submission to ICAO is beyond the scope of this project. Rather, it focuses on the initial steps of assessing the current state of data and determining what data needs to be gathered. This focused intent is elucidated by a discussion of the functional requirements (Table 1).

Table 1. Functional Requirements

Function	Description
The system will organize the client's existing digital aeronautical data	Clients need a procedure to load their current digital data into a database optimized for eTOD functionality
The system will generate the four required eTOD Coverage Area boundaries	After selecting the Area or specific airport, clients need to create new Coverage Area boundaries as defined by the eTOD rules
The system will provide methods to report on the assessment of a client's existing terrain and obstacle data	Clients need a method to analyze their existing terrain and obstacle data and compare these data characteristics to eTOD standards

As in any GIS, the initial requirement of this project is setting up the project data. Aeronautical data comes in a wide variety of types and formats. For this project, it is assumed that the client will have digital data compatible to load into a geodatabase optimized for producing the ultimate eTOD sets. For this prototype, data will not need to be converted and no digitizing will be necessary. The user should be able to utilize the core ArcGIS tools to load aeronautical data into the eTOD geodatabase. Inconsistencies between existing attributes and the geodatabase schema attributes are not critical at this stage as existing obstacle and terrain data will have to be upgraded later, or new data obtained to comply with the strict eTOD standards. In this initial stage, the user just needs a minimum of airspace and airport features to complete the remaining functional requirements. A description of this minimal data is found in Chapter 4 – Database Design.

Once the data has been loaded, the user needs to interact with the data to create the information necessary to proceed. For the planning functionality of this project, the user will work with just one area or airport. After this specific area or airport has been chosen, the user must assemble the appropriate eTOD defined boundaries, which demarcate the areas within which terrain and obstacle data must be obtained. Clients need a simple method to set up these four areas, each defined by very specific parameters of size and shape. Area 1 represents the entire nation or jurisdiction, so the user needs a way to select an existing national/jurisdictional boundary and convert it into a new obstacle area feature. Areas 2 through 4 delineate areas around a single airport, with progressively more focused extents and complex geometries. The client needs easy-to-use procedures to assemble these difficult boundaries, convert them to a single polygon border, and append them to the obstacle area feature set.

Creating these required area boundaries is the first critical step in appraising the magnitude of work necessary to assemble final eTOD sets. The assembled area delineation boundaries can now be used to segregate the existing terrain and obstacle data. Characteristics of data within these boundaries, such as vertical accuracy or survey dates, must be assessed to determine the suitability of the data for inclusion in an eTOD set. This assessment helps to support two critical tasks of preparing for eTOD compliance. First, it clarifies which existing data must be updated. And second, it confirms the extent and scope of the work to be done in compiling a complete eTOD set for the airport. In nearly every case, new surveying within these areas will be necessary. Knowing the exact boundaries within which to focus these costly efforts is invaluable to clients with limited resources.

Up to this point, the establishment of the eTOD areas has been carried out with a narrow set of aeronautical data. Except for national or jurisdictional borders, or maybe airspace boundaries, the analysis has been achieved with little to no geographical context. Creating maps to show the locations of the area delineation boundaries contextually would be a helpful tool for planning the data update and acquisition effort. Clients need a method to organize appropriate geographical data like aerial photos, political boundaries, and cultural features like road networks, and display them in a map overlaid with the area boundaries. Ideally, these maps would be integrated into a report to include tables listing data requirements for each associated eTOD area. These reports could then be used to inform requests for proposals for survey work or to help define the internal work plan.

Aggregating reports of all airports in the nation will help determine the overall budget and schedule for complying with eTOD.

Successfully implementing these crucial steps towards eTOD compliance – assessing current digital data, establishing eTOD delineation areas, and creating reports for eTOD compliance planning – fulfills the functional requirements of this project. But how the client wants these requirements to be implemented is also important. The next sections describe these non-functional provisions that ESRI have outlined for a typical eTOD client.

3.2.2 Non-Functional Requirements

This project must facilitate the easy and cost effective production of eTOD area delineations and planning reports, requiring a minimum of GIS expertise. As such, the following discussions of non-functional requirements (Table 2) focus on ease-of-use and efficiency. The GIS interface should be distilled to the basic functional tasks described above, and simple tools should be optimally designed for beginner users. Hardware and software requirements should be minimal, as practically possible. Operational requirements hinge on the timely production of the functions, as the ICAO deadlines loom near. And the simple implementation of this system underscores the transitional requirements of this project.

Table 2. Non-functional Requirements

Function	Description
Technical	
Computing environment	Desktop or laptop computer. No need for client/server or networking systems
Data hosting	On user hard drive
Computing requirements	Configured for typical ArcView performance
Software	ArcView 9.3 – no extensions
User interface	ArcMap and ArcCatalog
Operational	
User expertise	Limited to no GIS experience
Quick and efficient functions	Many airports to analyze. Deadlines looming
Short project lifespan	Limited need for updates, maintenance
Transitional	
Data	In ArcGIS formats, no conversion necessary
Testing of models and tools	Test functionality with new data sets

3.2.2.1 Technical Requirements

Since this project facilitates the initial planning stages of eTOD compliance and not the final distribution of complete eTOD sets, the technical requirements are very basic. As such, the technology required must be condensed to the bare essentials: desktop or laptop computer, ArcGIS ArcView software, and printer.

A typical client will analyze data and produce reports in-house, using agency personnel. They will only need to access the data and produce the reports from desktop or laptop computers. In most cases, data can be hosted on the hard drive of the designated computer. In cases where a large number of airports are to be analyzed quickly, an enterprise system may be preferable, to allow multiple users access to the data. However, for this prototype, it is assumed that area delineations and reports can be produced one at a time on an as-needed basis. The user should be able to simply print the reports and documents in house in a format compatible to their existing printers.

The hardware requirements must be matched to the specific nation/agency needs. In most cases, one desktop computer will be adequate. Necessary computing parameters must meet the requirements of reasonable performance for ArcView analysis and map making using ArcView layout designs. Hard drive capacity will be determined based on the extent of the aeronautical data required (how many airports, how many features at each airport, etc.). Most importantly, the system design should not rely on any expensive, customized, or specialized computer hardware or accessories.

As per ESRI’s request, ArcView 9.3 GIS software will be the core of the solution. To minimize client costs, the solution must successfully operate in this lowest license level of the ArcGIS product line. The project must not rely on any specialized tools or functionality that requires the purchase of software extensions. Any custom tools, scripts or models developed for this project must work in the ArcView environment. Users should access the models and scripts through the standard ArcView interface. This prototypical eTOD planning solution is intended to be an introduction to ESRI’s existing products, preferably leading clients to upgrade to the added functionality of their PLTS-Aeronautical Solution for final eTOD compliance.

3.2.2.2 Operational Requirements

It is assumed that users will have little to no previous GIS experience. As such, the workflow for using this solution must be carefully considered. Custom scripting, models and tools should be provided to facilitate easy creation of the area delineations and documents. Simple instructions and help should be easily accessible with every tool. With very limited training, personnel should be able to load data, query data, run models and scripts, produce maps and documents, and print them. As discussed in the technical requirements, the GIS interface should be simplified to focus only on the required tasks and outcomes.

The deadlines for producing the eTOD sets are fast approaching. So, quickly completing the initial planning tasks is imperative. Based on the size of the nation or jurisdiction, and the extent of aviation operations, many area delineations and subsequent reports must be produced and the workflow for undertaking these tasks optimized for speed and straightforwardness. GIS operations and any custom tools or methods must operate quickly and efficiently. Complicated procedures or the need for lengthy computation time will greatly diminish the benefits of this system.

The timeline of the project is strictly restricted by the eTOD compliance deadline of November, 2010. Therefore, this project will have a limited lifespan. Once the datasets have been produced, the functional requirements of the project will be complete. Maintaining, updating, and revising the datasets will be carried out in a future project and are beyond the scope of this one.

3.2.2.3 Transitional Requirements

Transitional requirements focus on the needs of the client when implementing the system. Important aspects of data preparation, user training, and system deployment must be carefully addressed. This transitional phase must be simple and expedient in order to guarantee a successful project outcome.

It is assumed that the required base data for this project will be in ArcView-supported formats. It is the responsibility of the client to gather the required data and to ensure its accuracy and usability for this project's functionality. In many cases, outside agencies may be able to provide the needed data. Any data conversion is outside the scope of this project.

Before implementing the system for clients, the project must be thoroughly tested, with area delineations and reports produced and examined. Custom tools should include dialogue boxes that warn users about improper data inputs, parameter choices, etc. Error messages should be friendly and helpful, making suggestions for remediation or pointing to important help documents. End users must be trained to use the software, but emphasis will be on completing only the steps necessary for eTOD dataset creation. The users should be able to easily report any bugs or defects in the software or workflow.

From a concise declaration of the client problem, and a comprehensive analysis of the client's requirements for the project, it is now possible to begin designing a system to respond to these challenges. The next section introduces the conceptual design for the prototype eTOD solution developed for this project.

3.3 System Design

This section addresses the computer hardware and software configurations selected for this project, and describes the technical solutions designed to meet the client's needs and objectives. The functionality of this proposed eTOD solution was designed specifically for end users with little to no GIS experience. The management, modeling, and visualization of the aeronautical data had to be accomplished with a minimum of steps and the most simplified procedures. Accomplishing these expectations resulted from the careful interplay of three major components: information products (project outputs), applications (functionality and procedures), and the system framework (hardware and software). A successful system design, like the architectural plans for a building, maximizes utility, and helps limit future problems in employing the solution.

3.3.1 Information products

The ultimate goal of a successful GIS solution is formulating useful information from user data. Information products describe how the system will fashion the delivery of this information. For this eTOD planning solution, two fundamental products will be delivered. First, a report assessing the characteristics of terrain and obstacle data for a selected area or airport will be generated. Data will be isolated into the four eTOD area boundaries and attribute and metadata information will be compiled in an 18” x 24” report format using ArcMap layout view. Second, eTOD clients need support materials to help plan for additional data collection and surveying. A second report will be generated listing the data requirements for applicable terrain and obstacle features within the designated eTOD areas surrounding the selected airport. The report will incorporate helpful contextual information, including aerial photos and thematic maps focused on the extents of the eTOD area boundaries. Once again, these reports will be designed for 18” x 24” format using ArcMap layout view. Creating these reports is the task of the system applications.

3.3.2 Applications

Providing effective and user-friendly applications to create the desired information products is a trait of good system design. For this client’s intended users, being able to use these applications quickly and effectively is the primary incentive to employ this project solution. Generating the information products rests on three fundamental procedures: organizing the data, analyzing and manipulating the data, and reporting the information construed from the data. The intent of this project is to implement these procedures in as few steps as possible, always keeping in mind the limited GIS experience of the end user.

The first step in creating the desired information is compiling and managing the data. For this project, two primary data sets were used. First, digital aeronautical data supplied by ESRI included existing terrain and obstacle data for select airports in California. These data were used to generate the four eTOD areas delineations. Also included in this data set were specific airport features like taxiway layouts for the Salinas Municipal Airport, which acted as the test case for this project. A file geodatabase was designed to organize this aeronautical data, with a schema optimized for eventual eTOD submission. A second set of data was collected to support the reporting functions of the project. Aerial photography for the Salinas area was assembled and organized. Specifics on the design of the geodatabase, and data sources and details are explained in Chapter 4.

Compiling and organizing the project data into a geodatabase is just the first step in transforming it into useful information. Developing useful information comes from the thoughtful manipulation and examination of these data – data analysis. Analysis for this project focuses on one primary function – creating the four eTOD area delineations. This system uses Model Builder to assemble four specific models that will allow the user to select an area or airport, construct the area boundaries appropriate to the chosen area, and append this boundary to an expanding collection of obstacle area features for the entire nation or jurisdiction. Once these boundaries are generated, they are used to clip or isolate data within the borders. This segregated data can then be validated against eTOD requirements. The boundaries will also be used to generate the extents of the contextual aerial photos and thematic maps to be incorporated into the planning reports. The specific functions and tools of the area delineation models are described in detail in Chapter 5.

3.3.3 System Architecture

The project system architecture is characterized by the selected configurations of computer software and hardware. The client was very specific about these configurations. They did not want this project to compete with the PLTS – Aeronautical Solution. Instead, they intended the project to be an introduction to their suite of software, representing a first step, an inexpensive planning guide for the eTOD mandates. They therefore mandated that the solution use the lowest license level ArcView software and that no extensions to the software be required. The system was designed for a standalone desktop environment, with the data hosted on the user's hard drive. The host computer must be able to run ArcView efficiently, with the minimum requirements recommended by ESRI, like 1 GB of RAM and a 1.6 GHz processor. No networking or client/server configurations were required. The project was designed using the ArcGIS 9.3, Service Pack 1. The applications are accessed using ArcMap and ArcCatalog in the ArcView environment. The reporting functions are carried out with templates utilized in ArcMap layout view. Details of this system architecture can be found in Chapter 5.

The determinations of the previous systems analysis and design sections lead to planning for a successful project completion. In the next section, the project plan is outlined in detail.

3.4 Project Plan

This section outlines the original plan for accomplishing the goals and objectives of this project. Tasks and subtasks deduced from these preliminary intents are presented chronologically, and the initial estimated time frames for completing these tasks are indicated, although many tasks were planned to occur concurrently. The following chart (Figure 3.1) introduces and summarizes the project tasks and workflow detailed in this section.

Of course, the preliminary project plan was revisited and subsequently revised frequently through the duration of this project. Discussions of these revisions, observations, and lessons are given below.

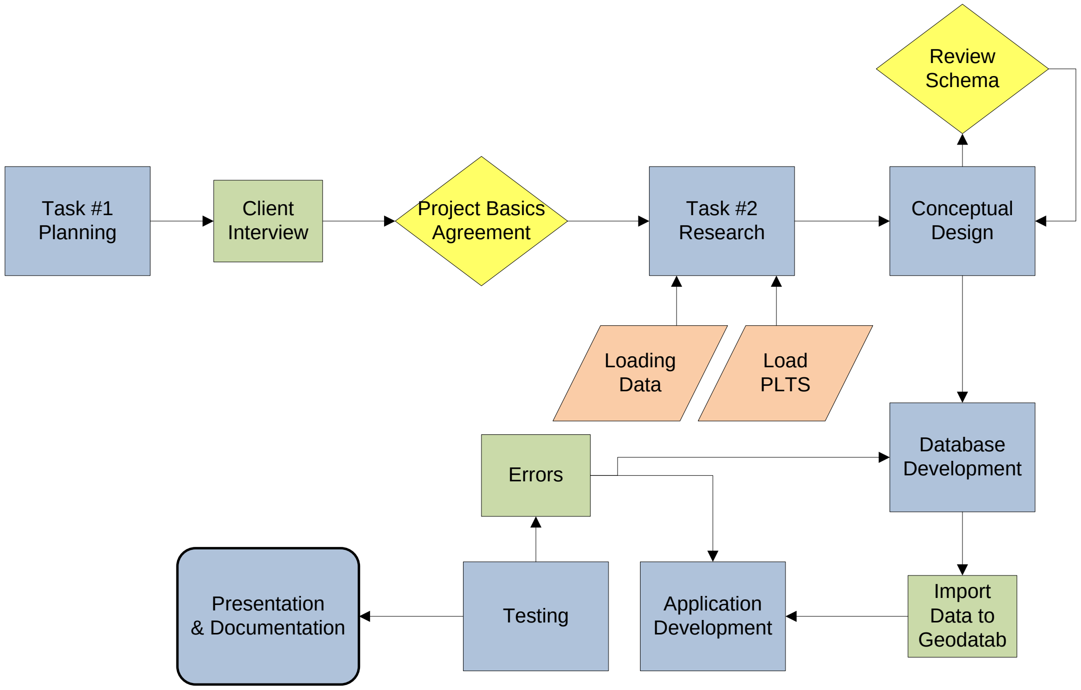


Figure 3.1: Project Plan Tasks and Workflow

3.4.1 Task 1 – Planning

Estimated time frame – 4.5 months
The primary task during this initial phase was assessing the needs of the client. A first set of interviews with ESRI staff established the groundwork for creating a project proposal, highlighted by a carefully crafted statement of the client's problem. Having a precise understanding of what the client wanted to accomplish in this project crucially informed all subsequent steps of the project. From this knowledge, a preliminary solution could be formulated. The ultimate success of this solution will be assessed by its ability to address the specific goals and objectives of the client honed in this proposal. An agreement on the scope of the project was also established– exactly what and what not the project promised. And finally, an outline of probable methodologies for solving the client's problem was proposed. The entire proposal, with cooperation from the project committee and client, acted as a de facto contract – a yardstick for project progress and incremental success.

Solidifying project assumptions and conclusions in the proposal allowed for the formation of a work plan. An arrangement of subtasks, milestones, and deadlines for deliverables was established to set the allocation of effort necessary to complete the project. A schedule was proposed for completing these tasks, indicated by the duration of these tasks, and specific dates for crucial milestones and deliveries to the client were set. Important linkages between tasks were determined in order to determine the implications of delays on future related tasks. Throughout the duration of the project, the work plan was continually referenced and updated to reflect the realities and challenges encountered.

3.4.2 Task 2 – Research

Estimated time frame – 5 months
The second phase of the project was completing the research tasks. Here, published methodologies and strategies comparable to this project were examined, materials and documents relative to the eTOD mandates were reviewed and assimilated, and a literature review of the history of aeronautical data management, and the origins of the eTOD mandates was undertaken. ESRI provided extensive documentation of the International Civil Aviation Organization's eTOD standards and procedures. These were carefully evaluated in the context of the project objectives. In addition, a web-based interactive schema for the Aeronautical Information Exchange Model (AIXM) furnished by ESRI was carefully analyzed and deconstructed to inform the design of the eTOD geodatabase.

ESRI designed custom tools for its PLTS – Aeronautical Solution to address the eTOD mandates. An evaluation version of this software was installed on the project computer. Included in this installation was the digital terrain and obstacle data to be used for the project test case, as well as the requisite aeronautical data, such as runway configurations. The PLTS software incorporates an Aeronautical Information Systems (AIS) SDE geodatabase schema which served as the basis for the eTOD database. Tools special to PLTS, used to delineate the four airport obstacle areas to be created for eTOD, were investigated for insights into creating the customized models and scripts for the project implementation.

One of the most difficult challenges faced during this research phase was gaining an adequate understanding of the aviation context of this project. The wide range of systems and procedures, intersecting stakeholders, and arcane terminologies of modern aviation made it difficult to focus on the salient issues and imperatives of the eTOD mandates. After months of immersion in eTOD and aeronautical data, it became clearer how the eTOD initiatives fit into the narrative of air traffic control, and how its mandates specifically address the future of traffic management. The eTOD regulations continue to be revised and updated. Significant revisions to the area 2 geometry were issued during the project execution, as was an update AIXM. Unanticipated time was spent keeping track of these updates and changes, as well as deciding how much these revisions should alter the project progress. Once it became apparent that the eTOD rules were in actuality an unanticipated moving target, discussions with the client most often resulted in moving ahead with the original specifications.

3.4.3 Task 3 – Conceptual Design

Estimated timeframe – 3 months
The previous planning, research, and discovery tasks paved the way for development of conceptual designs for the eTOD geodatabase and application methodology. Based on the thorough review of eTOD documents, the AIXM schema, and the PLTS geodatabase, a conceptual geodatabase was formulated and diagrammed using Microsoft Visio. The requisite feature classes, feature datasets, tables, and relationships were established.

Conceptual approaches for creating the four airport areas were also carried out. Methods were explored for using core ArcGIS tools to create the obstacle area delineations. The potential steps and functions of this core functionality were assembled into preliminary models (for each area delineation), using the ArcGIS model builder technology.

For the most part, the conceptual design for the project held fairly true to the original hypothetical plans. The design did indeed focus on the creation of the four obstacle area designations. However, one of the original plans to devise a method for creating ICAO formatted charts of the eTOD information was dropped soon into the project. ICAO's requirements for this new type of charting were not finalized in time to incorporate, and ESRI determined it was unnecessary to provide this functionality using the old standards of charting. Moreover, these charts require three-dimensional analyses and diagramming which are unattainable without using additional extensions and higher license levels of ArcGIS. ESRI was willing to eliminate the charting functions, rather than compromise their imperative to use ArcView and no extensions for this project.

3.4.4 Task 4 – Database Development

Estimated time frame – 2 months
The conceptual geodatabase was built based on the earlier research phase, and reviewed by the client. All necessary steps, such as creating feature classes and relationships, were carried out for assembling the geodatabase using ArcCatalog. Upon completion, it was evaluated by a thorough cross-check of the AIXM schema and the eTOD documents.

Emphasis on the importance of the geodatabase and its actual necessity went through many stages during the project process. Organizing the aeronautical data was not essential in creating the area obstacle delineations, as the data was delivered in an SDE database with its own logic and schema. And as the emphasis on creating a planning solution gradually strengthened, the significance of creating an eTOD geodatabase decreased. This database would not be used for the final eTOD submission sets, and the great variety in data types and formats anticipated to be used by various clients made it difficult to create a best fit database solution. At one point, building the database was going to be abandoned. However, it soon became evident that the functionality of creating new obstacle boundaries and using these features for subsequent functions like clipping existing terrain and obstacle data, was greatly enhanced by organizing the data, both existing, and created, into a file geodatabase. While this eTOD database would not represent the final submission, it would be a great help to users to begin to format and organize the data as a step towards this goal. Organizing the report data like the aerial photos and cultural features also greatly enhanced the processes for creating these reports.

3.4.5 Task 5 – Application Development

Estimated time frame – 2.5 months
While building the geodatabases went through much iteration, the methodologies for establishing the airport obstacle area delineations continued to be finalized. The data provided by ESRI in Task 2 were used as a test case for running these applications. In the end, models were built for each of the area delineations using Model Builder technology. Optimal tools and functions were selected from the core ArcView toolbox to build the areas boundaries most expediently. Implementing custom scripts or programming for these tasks turned out to be unnecessary, contrary to initial assumptions.

Creation of the four obstacle area delineation methods was the greatest challenge, as anticipated. However, several circumstances along the way helped to mediate some difficulties. Using the PLTS – Aeronautical solution turned out to be very helpful (especially the Task Assistant tools) in evaluating ESRI's earlier efforts to address eTOD. While PLTS offers advanced tools and functionality, studying the process of creating the four areas was invaluable in shaping the methodology for the ArcView environment. The full ArcEditor license software was accessible throughout the duration of the project, but ArcGIS Desktop Manager was used to turn off this functionality and work solely in the ArcView environment. In addition, all available extensions were disabled. This forced the project to be developed exclusively with ArcView core tools, as requested by ESRI.

After initial study of the eTOD rules and regulations, work focused on the specific configurations of the four area delineation geometries. The shape of the Coverage Area 2 boundary is in actuality three-dimensional. It most simply resembles a graduated cone, with the narrow tip at the center of the airport, rising at a constant percent slope to the margins. This in effect mimics the ascent and descent of aircraft. After some research and discussion, it soon became apparent that creating a three-dimensional surface representing this complex geometry was unworkable in ArcMap, especially in the ArcView environment. After consultation with the client, a compromise emerged. Since this solution would be used for initial planning, a delineation of the extent and shape of the margin, not its three-dimensional qualities, would be sufficient for this initial stage. Establishing this border was still useful in showing the size and shape of the area in which data must be collected.

Two major changes in application development emerged during the project process. First, creating ICAO charts, once thought to be an essential function, was dropped early on. It quickly became evident that the ICAO standards for this charting would not be finalized in time to incorporate into this project, and three-dimensional analysis would be necessary to adequately assemble the charts, adding software requirements that ESRI objected to. Charting would ultimately be a test of the quality of the final eTOD sets, and as this project transformed into a planning solution, such testing became superfluous. Second, the value of assessing existing data and planning for additional data collection became more apparent, so creating useful reports to aid in these important planning tasks was now a priority. The contextual data and its organization and analysis became more important, as did creating a method to make these reports. This shift in emphasis required reallocating resources and revising the project plan.

3.4.6 Task 6 – Testing

Estimated time frame – 1.5 months

The geodatabase design, area creation procedures, data analysis, and reporting techniques were tested for completeness and applicability. ESRI provided additional national aeronautical data sets as supplementary cases for this testing phase. These data were loaded into the eTOD geodatabase just as a potential client would do. Each Model Builder case for creating the four respective airport areas was run, errors were assessed, and modifications were performed. Tests were run iteratively until a successful solution was completed.

3.4.7 Task 7 – Project Presentation & Documentation

Estimated time frame – 4 months
These final tasks were completed to satisfy the requirements of the MS GIS Program, finalize the project documentation, and distribute project deliverables to the client, ESRI. As one of the MS GIS requirements, the project was presented at the ESRI User Conference on July 15, 2009. This provided an invaluable opportunity solicit public feedback on the project and incorporate helpful suggestions and revisions into the final product. Gaining on the experience of this public presentation, the project was again presented, this time before the project committee at the MIP Defense on August 6, 2009. Changes and recommendations gleaned from this proceeding, as well as comments from reviews of drafts, were incorporated into the final MIP document. The completed MIP document and any remaining deliverables were finally presented to the client, marking the successful conclusion of the project.

3.4.8 Project Plan Review

In retrospect, the planning stage of the project proved to be invaluable in shaping the course of the project, remaining a touchstone for assessing progress and keeping focus on a clearly defined scope, goals, and objectives. When the inevitable changes and redirections occurred, the plan and schedule helped in deciding what was possible, and what needed to be redefined or discarded. Surprisingly, the scope of the project was actually reduced, after the shift of focus to a more planning-oriented functionality for the project.

The change and refining of the scope evolved mostly from two specific events. First, the ICAO and responsible eTOD committees and stakeholders continued to redefine and hone the eTOD requirements; a worldwide dialogue continues to shape the implementation of eTOD, and it became clear that this project could not provide a final solution for eTOD. Throughout the duration of the project, much of the discourse on eTOD focused on the difficulties and costs in collecting the required data. ESRI began to see that a solution providing valuable tools to help in gathering this data might be most desired. Second, about three quarters of the way into the project, ESRI issued their PLTS – Aeronautical Solution eTOD methodology. This helped to reinforce the introductory nature of this project, providing first stage functionality for potential clients of the PLTS solution.

In addition to, and supported by, the reemphasis on planning functionality, application development shifted from creating charts to creating planning reports. This was reinforced by having to abandon any three-dimensional analysis, a quickly discovered provision of charting and creating complete obstacle area delineations. A new emphasis on contextual data, its organization into a geodatabase, and its enhancement of the reporting function soon emerged. Assessing current terrain and obstacle data, and planning for additional data collection, became the primary aim of the project. Still, this worked to reinforce addressing the original problem statement of providing a low cost, first step alternative for clients with limited resources.

3.5 Summary

The preceding sections outlined ESRI’s motives and intentions for this project. An analysis of their requirements for the completed system was established through a thorough understanding of their goals and objectives for an introductory eTOD GIS solution. These requirements coalesced into a conceptual design for the system, from a discovery of desired information products, to the configurations of computer software and hardware. And finally, the project plan outlined the strategy for successfully implementing these requirements and successfully completing the project. The fundamental purpose of these discussions was to clearly set out expectations and provide a roadmap for evaluating the eventual implementation, outcome, and conclusions of this project. In the remaining sections of this report, the discussions will turn from the original project intentions, to what actually emerged during the efforts to complete the project. This refocused discourse begins with an outline of how the databases were designed.

Chapter 4 – Database Design

Initially, the task of designing a database for this project seemed daunting. The project was, for all intents and purposes, designed for clients of whom we have no idea what kind of data they will be using for this project. Since aeronautical information is currently not required to be derived from a digital database, the formatting and data types of a client's data will be very unpredictable. The inspiration for the database design would have to start from a different perspective, the perspective of eTOD compliance. The eTOD regulations are very clear about what type of geographic features must be used to generate the four Coverage Areas. They are also explicit about required attributes and formatting of terrain and obstacle data. These mandates would become the focus of the database design. And as this project is intrinsically an introduction to the ESRI Aeronautical solution products, it seemed obvious that the data used for this project should be comparable to PLTS solution data. With these decisions formulated, the process of creating the database design could begin.

This chapter introduces the sequential steps used to determine what data was required, how it should be organized, where to get it, and how to prepare it for use. The first section describes the efforts to develop a conceptual data model. Progressing from this conceptual phase, a discussion of the creation of the logical data model follows. The structure of the geodatabase is outlined, and the database features and their attributes are introduced. The sources for the project data are presented, as well as the methods used to collect these data. Finally, the procedures to prepare and load these data for the project applications are put forward.

4.1 Conceptual Data Model

The conceptual data model for this project originated from questions about the fundamental requirements of the project. What geographic data was essential to meet these functional requirements? What types of analyses were being proposed, and how would data organization influence these analyses? What information needed to be gleaned from this selection of data? What were the actual tasks to be performed by this project, and how would the selection of data enhance these steps? And most importantly, because of the magnitude and complexity of aeronautical data, how could a data schema be developed to simplify the initial steps of eTOD compliance? The first step was to analyze the functional requirements and conceptualize a data schema to effectively perform these functions.

The functional requirements for this eTOD project were threefold. First, a client needs to load their current digital data. Second, they need to create the obstacle Coverage Area boundaries as defined by the eTOD regulations. And third, they need to utilize these boundaries to analyze their existing data as compared to the eTOD data requirements. Accomplishing these functions with minimal data collection and efficient use of these data were the goals of the conceptual data model phase.

As stated before, since there is no way to predict what type of data a client will bring to the project, the conceptual model had to start with creating a prototype eTOD database. An eTOD database had to be developed to facilitate the easiest transfer of terrain and obstacle data to a final eTOD submission set, the ultimate goal of a complete GIS eTOD solution. It had to be an efficient container of the minimum set of data needed to accomplish this goal. Consequently, the conceptual organization of the database would be relatively simple (Figure 4.1). The geodatabase had to provide an organizational schema for importing a client's existing digital aeronautical data. In addition, it needed to organize both user-provided data, as well as solution specific data necessary to run the tools used to create the Coverage Area polygons. And finally, a schema had to be developed to incorporate the eTOD required attributes for the obstacle data types.

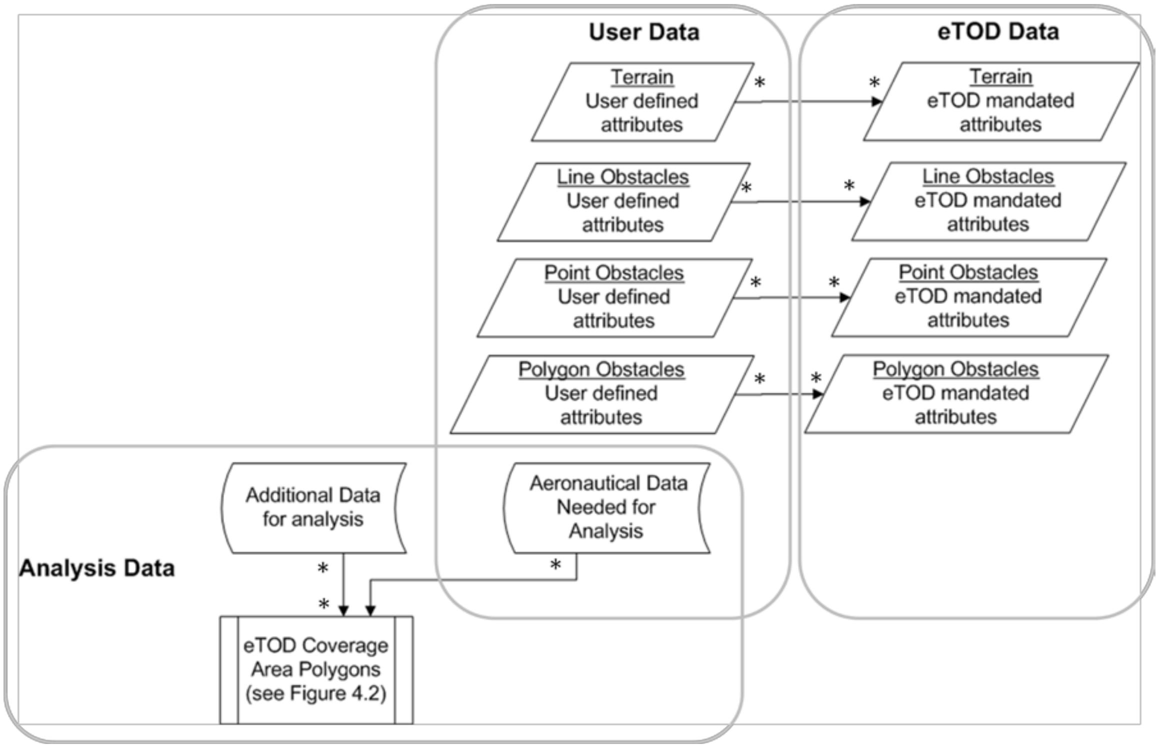


Figure 4.1: eTOD Conceptual Data Model

To further develop the conceptual data model, a diagram was created to identify the features required to generate the eTOD Coverage Area polygons. By reading the ICAO eTOD guidelines, one could note the verb and noun usage in the Coverage Area descriptions to identify an outline of needed data and how these data interrelate. The following diagram (Figure 4.2) graphically depicts the outcome of this notation. Illustrated are the entities required to create these boundaries, as defined by the eTOD guidelines, as well as their relationships to each other. The eTOD guidelines do not impart specific data types or data formats, only the real world objects that underpin the formation of the Coverage Areas. Re-examining this diagram proved very helpful during the process of developing the logical data model.

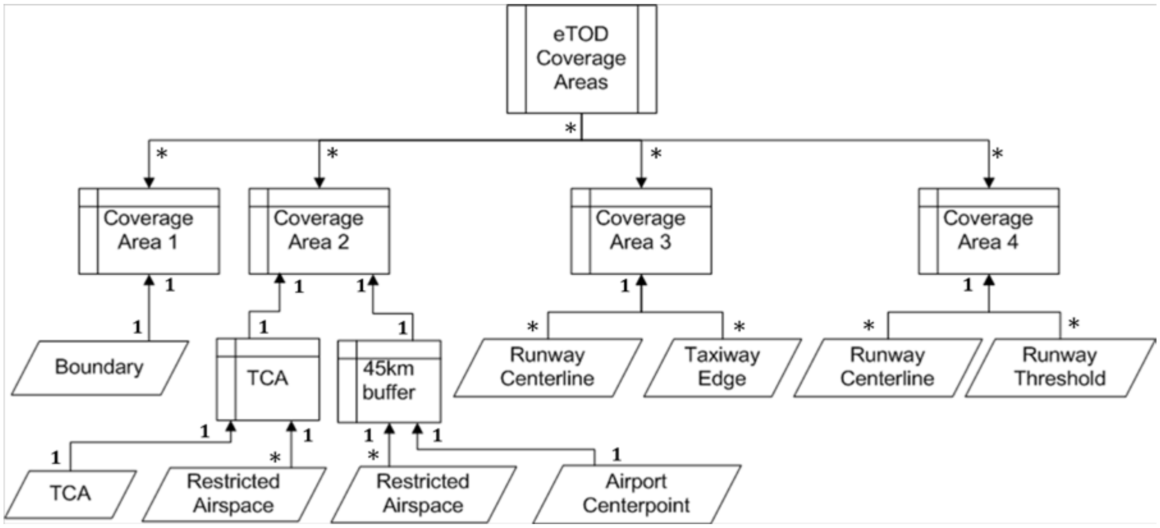


Figure 4.2: Coverage Area Data Concept

4.2 Logical Data Model

The logical data model springs from the theoretical framework of the conceptual data model. Here, the previous abstract concepts are realized in the physical design of a database. Required feature classes and table are determined. Choices are made about attributes for these features. For this project, a file geodatabase was eventually chosen as the preferred organizing framework for the chosen data.

4.2.1 eTOD_obstacle File Geodatabase

Through a long period of trial and error, and successes and missteps, the eTOD_obstacle materialized as the optimal organizer of the project data. It started as a carbon copy of the PLTS – Aeronautical Solution tutorial SDE geodatabase, which will be explained in section 4.3 later in this chapter. This geodatabase is rich with aeronautical features formulated for ICAO aeronautical charting, a good starting off point for creating an eTOD geodatabase. The file geodatabase format was chosen for its simplicity of use in ArcView, and its unlimited storage capacity to contain very large amounts of data for all a country's airports.

Deciding on the final design for the geodatabase was a back and forth process of compromising and editing. The full PLTS database was first used to start creating the Coverage Area tools, but as these progressed, it became evident that the database could become much simpler. Once the models were working well, the geodatabase was stripped to the core components. What evolved was a simple organization of three feature datasets (Figure 4.3): context, coverage_area, and obstacles. These datasets arrange the features in logical groups. The three geometry type obstacles are grouped together as the ultimate outcome data of this project. The coverage_area feature sets collect all the required features needed to run the Coverage Area tools. And the context set locates the ancillary background data to help give the complex aeronautical data a geographic foothold. Each of these features is described in detail in the following sections.

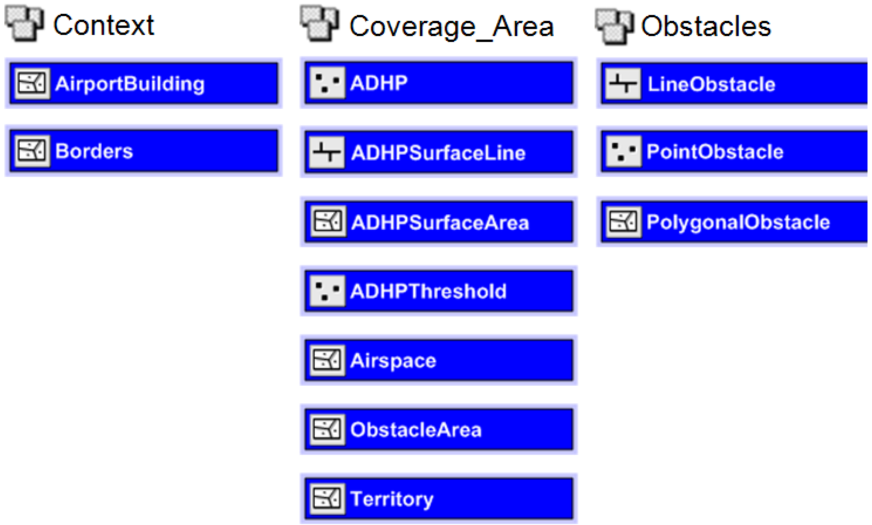


Figure 4.3: eTOD File Geodatabase

4.2.2 Obstacle Feature Dataset

The most important data for an eTOD application is the obstacle data. When the eTOD mandates adopted the latest Aeronautical Information Exchange Model (AIXM), it simultaneously accepted the new ability to represent obstacles in their more intrinsic form – lines, points and polygons, where before obstacles could only be represented by points. So in this eTOD database, a feature dataset includes features representing these three obstacle types: LineObstacle, PointObstacle, and PolygonalObstacle (Table 3). Line obstacles use lines to represent features with a pronounced linear and horizontal geometry, the best example being elevated electrical wires. In contrast, point obstacles have little to no horizontal extent, such as light poles or cell phone towers. Polygonal obstacles, like line obstacles, have significant horizontal extents, but are not linear. They have width and depth, like buildings and are best represented by a polygon shape. Each of these feature types share many similar attributes, but because of individual geometry, have attributes specific only to them.

Aeronautical data have many attributes associated to them. Both the ICAO aeronautical information standards (for processes like charting), and the eTOD mandates establish lists of required attributes and their data format requirements. A list of these attributes is too lengthy to include in this document, but a few significant attributes will be presented for each feature type to illuminate their special qualities. All three obstacle types share a common list of attributes, highlighted by those in Table 3. Horizontal resolution and accuracy are primary attributes as they signify a fundamental purpose of eTOD – establishing data quality standards for each Coverage Area. Of course there are a good many attributes associated with the elevation of the features, like ELEV_VAL, an important distinction in determining if a feature is to be included in an eTOD set. Each obstacle type has specific attributes associated with its particular geometry. For example, line obstacles include a specific length field, while point obstacles have a special radius value field which gives a radius of a circle around the center of the obstacle, to include associated structures like guy wires. With a data set established for the obstacles themselves, a dataset then needed to be established for creating the Coverage Areas that will be used to segregate the appropriate obstacles.

Table 3. Obstacle Feature Dataset - Features

Feature	Significant Attribute	Attribute description
LineObstacle	SOURCE_TXT	Name of entity or organization that supplied data according to ICAO Doc 9881. In case of initial data origination, name of data originator.
	HRES_VAL	Horizontal resolution of coordinates (latitude, longitude) defining the feature.
	HCONF_VAL	The probability that the position values are within the stated horizontal accuracy of the true position.
	ELEV_VAL	Maximum elevation of the top of object.
PointObstacle	Same as LineObstacle, except for specific attributes applicable only to point features	
PointObstacle	Same as LineObstacle, except for specific attributes applicable only to polygon features	

4.2.3 Coverage_Area Feature Dataset

The Coverage Area feature dataset is the most comprehensive of the three datasets. The features found within denote a minimal set of data necessary to create the required Coverage Areas. All but two of the features, obstacle_area, and territory, are standardized aeronautical information data readily available, but not always in digital form. In some cases, like Coverage Area 3, which delineates a buffer from airport surface area edges and centerlines, the eTOD rules required using a specific type of data, like ADHP_SurfaceLine for runway centerlines. In other cases, data was selected to most easily generate the Coverage Area shape. The discussion of this dataset will outline the conventional aeronautical data organized by shape, and will end with a look at the special features, obstacle _area and territory.

Except for obstacles, aeronautical data has been represented by the common shapes of point, lines, and polygons. Point data is very important in establishing exact, pinpoint locations and/or elevations of significant airport features, like the geographic center point of an airfield. The two critical point features for this project are ADHP and ADHP Threshold (Table 4). As a prefix acronym, like ADHP-Threshold, ADHP stands for Aerodrome/Heliport. But in this dataset, the standalone ADHP point feature denotes the ICAO determined center point of the entire airport. More specifically, it is the geographic center of the area covered by the active runways. Location and elevation data accuracy are critical for this feature, and thus attributes for these characteristics are vital. Like ADHP, ADHPThreshold establishes another essential airport feature, a runway marker indicating the landing touchdown point. Among many important characteristics of this feature, it gives the name for each runway end. These names (DESIGNATOR_TXT) give the magnetic bearing of the approach runway. For instance, RWY 13 means that a pilot is approaching a runway that is 130 degrees clockwise from magnetic north. This point feature is essential in generating Coverage Area 4, specifically established for airports with instrument landing capabilities.

Table 4. Point Features - Coverage_Area Dataset

Name	Significant Attributes	Attribute Description
ADHP	GEOACCURACY_VAL	The horizontal distance from the stated geographical position within which there is a defined confidence of the true position falling.
	GEOACCURACY_UOM	A code stating the unit of measurement for the value expressing the accuracy of the geographical coordinates. For example, M is for meters
	ELEV_VAL	The vertical distance to the highest point on the landing area of the aerodrome from Mean Sea Level (MSL).
ADHPThreshold	DESIGNATOR_TXT	Textual description of the ADHP Threshold designator.
	TRUEBEARING_VAL	The value of the true bearing.
	TDZELEV_VAL	The numerical value for the Touch Down Zone Elevation.

One line feature is fundamental to the eTOD regulations, the runway centerline. Both Coverage Area 3 and 4 rely on the runway centerline to anchor their boundary shapes. In aeronautical data, the centerline is represented by ADHPSurfaceLine (Table 5). The runway centerline is but one of three surface line subtypes: runway, final approach and takeoff area (FATO), and taxiways. At a runway, the centerline is established by connecting the opposite threshold points. This ensures an accurate bearing for the centerline. Unlike most aeronautical data, the attributes for this feature are minimal, as this feature is more or less a reference to other established location points and features. Still, it is an indispensable feature for creating the eTOD Coverage Areas.

Table 5. Line Feature - Coverage_Area Dataset

Name	Shape	Significant Attributes	Attribute Description
ADHPSurfaceLine	Line	LASTMOD_DATE	Date on which the feature was last modified.

In addition to point and line features, generating the eTOD Coverage Areas requires an additional two polygon features – the surface area of the airport, and the airport airspace. The surface area of the airport is the ground plane on which aircraft move about the facility. This area, usually denoted by the shape of the runways and taxiways, is utilized in creating Coverage Area 3. In this model, the ADHPSurfaceArea_C (Table 6) feature is used. This is a special case of data in that it is a feature specifically designed for cartographic functions, especially for charting, thus explaining the suffix _C added to the name. These features accurately draw out the shape of the movement areas, and these shapes can buffered to establish the boundaries of Coverage Area 3. The other polygon feature is not a surface feature, but represents a special case of restricted airspace above designated airports. There are many designations of airspace, from regional to sector airspace, and many different shapes and sizes, with varying lower and upper elevation limits. For the purposes of eTOD, two designations are critical – terminal control areas (TMA), and restricted airspace. Terminal control areas usually are located at the confluence of airways, and area usually major airports. Restricted airspace is a zone where commercial air traffic cannot fly, such as areas with military use, or especially dangerous zones like certain mountainous areas. ETOD Coverage Area 2 utilizes the shape of an airport's airspace as one option for generating the area boundary. This project uses the attribute TYPE_CODE to isolate TMA airspace.

Table 6. Polygon Features - Coverage_Area Dataset

Name	Significant Attributes	Attribute Description
ADHPSurfaceArea_C	WIDTH_VAL	The value of the width of the surface area.
	MARKING_TXT	Textual description of the surface area marking.
Airspace	TYPE_CODE	Acronyms used to describe the type of airspace, i.e. TMA for Terminal Control Area
	ICAO_TXT	The four letter coded location identifier as published in the ICAO DOC 7910 - Location Indicators.

The final features in the coverage_area dataset are not typical aeronautical data, but special case features necessary for establishing the four eTOD Coverage Areas (Table 7). The obstacle area feature, a polygon, is the primary feature the project is attempting to establish, the specific shapes of each of the Coverage Areas. Each Coverage Area generated through the project applications will be appended to this feature class, creating a comprehensive collection of Coverage Areas for the territory. A subtype code, TYPE_CODE, will designate what type of Coverage Area has been created. A special case of obstacle areas is Coverage Area 1 which utilizes the political boundary of the territory being analyzed. Attributes for this feature are not essential, beyond the name of the territory, as the most salient characteristic is the boundary itself. While the essential features of the obstacles and coverage_area datasets were required for the project applications, additional data, such as aerial photos, were added to supply a contextual background for the Coverage Areas generated.

Table 7. Special Case Features: Coverage_Area Dataset

Name	Significant Attributes	Attribute Description
ObstacleArea	TYPE_CODE	Indicates the obstacle Coverage Area, for example Area 4
Territory	STATE_NAME	Text description of name of territory

4.2.4 Context Feature Dataset

Except for the territory boundary used for Coverage Area 1, the data used for this project only shows the location of airport features like runways and airspace. Except for users with intimate knowledge of the location of airports in reference to a national border, there is little to anchor these features to familiar features like topography or political boundaries. The final two datasets of the eTOD geodatabase provide a minimal set of data to establish this geographic context. In the context feature dataset (Table 8), two polygon features were added: airport buildings, and political borders. The AirportBuilding feature helps fill in the blank spaces in the ADHPSurfaceArea_C feature where the buildings would go, and helps present a more realistic rendering of the airport facility. The borders feature class can represent any number of political boundary features, from surrounding country boundaries which share airspace delineations, to smaller jurisdiction boundaries like states or provinces. The AirportBuilding feature is a typical aeronautical data type, while the borders feature is a suggested feature type left up to the discretion of the user.

Table 8. Features - Context Feature Dataset

Name	Selected Attributes	Attribute Description
AirportBuilding	TYPE_CODE	A numerical code indicating the type of building. For example, 2 represents a Fire Station
	CONDITION_CODE	A numerical code indicating the condition of buildings at the airport. For example, 1 means under construction
Borders	STATE_NAME	A text description of the name of the state or country

4.2.5 Raster Data

The final data chosen for the project were raster data added to the eTOD geodatabase to provide additional context and background to the Coverage Areas. Background for Coverage Areas 1 & 2 was provided by a georeferenced image of world landforms with a resolution of 1 km, adequate for the large size of these two Coverage Areas. For the near in areas surrounding the airport for Coverage Areas 3 & 4, a finer resolution aerial photo was used at extent to provide a complete background for both Coverage Areas. These images were imported into the geodatabase, but a typical user could even use an on-line map service to accomplish this. The use of these data is up to the discretion of the client.

When the first test of the Coverage Area models were run and the prototype Coverage Areas were generated, it became clear that the resultant map output needed a background on which to visually reference the location and extent of the created boundaries. Choosing an appropriate background relies on the client's specific needs. Perhaps it would be more appropriate to show land use, or political boundaries. Out of several options for aerial images, a digital orthophoto quadrangle (DOQ) was chosen for Coverage Areas 3 & 4 backgrounds. The DOQ was chosen for its high (1m) resolution and appropriate extent, an approximate 25 square mile rectangle, sufficient for use as a backdrop for both Coverage Areas. DOQ's are georeferenced, making them easy to use in the "on the fly" projection of ArcMap. With image displacement caused by terrain relief and camera tilt being removed in DOQ's, along with georeferencing, they combine the qualities of photographs and maps.

4.3 Data Sources

With the benefit of having ESRI as a client, they provided nearly all the data for project. Because of their considerable experience working with aeronautical information in establishing their PLTS – Aeronautical Solution, they have developed extensive models and schemas for digital aeronautical data. Their latest release included data models for the line, polygon, and point obstacles mandated by eTOD and supported by the latest version of AIXM. An extensive set of tutorial data is provided with the PLTS installation discs. These data were the foundation for this project.

The tutorial data used in this project is organized in an SDE database called ASPm, an acronym for Aeronautical Sample Production. It is optimized for aeronautical charting functions, and includes over one hundred features, tables and relationship classes. These data are formatted with a complex set of attributes, domains, and subtypes to comply with ICAO aeronautical information regulations, and work with the AIXM model. An SDE database is used because many fields have code designations that are very long, and the SDE configuration permits their use. The features are loaded with data from the southwestern United States, focusing on the state of California. The most detailed data, like taxiway configurations and airport buildings, are provided for the Salinas Municipal Airport in Salinas, CA. This airport was used as the test case for this project. A small additional set of data was obtained to support the Coverage Area creation functions, and provide a contextual backdrop to the abstract shapes of much of the aeronautical data.

The added data sets came from a variety of sources. The polygon feature called borders came from the ReferenceData file geodatabase provided with the PLTS tutorial data. A variety of background images, like digital ortho quads, were initially collected for contextual information, but were not used in the final solution. What was finally used was the world imagery layer file from the online ESRI Resource center. This layer file provides satellite imagery for the entire world, and high resolution aerial imagery, at resolutions up to 1 meter. This layer presents satellite imagery for the world and high-resolution aerial imagery, and works as a very realistic and easy to use backdrop for the aeronautical data in this project.

The metadata for these data is very minimal. Good descriptions of the features and their attributes can be found in the PLTS desktop help which has a very complete data dictionary. The eTOD regulations set up very strict standards for metadata for the eTOD sets. They are an amalgam of AXIM, UML, and ISO 19115 metadata standards. They set up specific categories for inclusion, which include: identification, quality, maintenance, spatial representation, reference system, distribution, extent, and citation and responsible party. Within each category, specific elements are required, like a contact person for information about maintenance of the resource (ICAO, 2007a). Creating this metadata is beyond the scope of the project, but any existing metadata that conforms to these regulations must be included.

4.4 Data Collection Methods

Since most of the data for this project was provided on the PLTS tutorial disc, the collection phase for this project was minimal. The PLTS – Aeronautical Solution software was installed on the project computer in order to explore the PLTS eTOD tasks in the Task Assistant Manager interface. The tutorial geodatabases were also installed at the same time. The aeronautical data in these geodatabases was accessed through ArcCatalog, through a connection with SQL server.

The contextual data for the project had to be collected from a source other than the PLTS tutorial data. Initially, to find a land use background for Coverage Areas 1 & 2, the ArcGIS 9.3 data from the installation discs was explored. Navigating to the world_images folder (ArcGIS 9.3\Elevation Image Data World\world_images), a three band color image was chosen, earth_1km. jp2, with an adequate resolution of 1 km and a realistic rendering of earth forms. For Coverage Areas 3 & 4, a much higher resolution image was needed for the smaller extent of these boundaries.

To locate the appropriate digital ortho quad (DOQ) for the Salinas Municipal Airport, the California Spatial Information Library was accessed through their website at http://casil.ucdavis.edu/casil/. Using their interactive mapping tool, the CERES GeoFinder, the place name for Salinas was selected, which brings up an aerial photo of the Salinas area. Clicking on the link to DOQQS, the two associated quads are displayed, with the eastern Natividad quad covering the airport area. From here, you can download a geotiff of the appropriate quarter, in this case the southwest quarter (36121f5sw). This image was loaded into ArcMap to see if it covered the entire extent of the airport area and the generated Coverage Areas 3 & 4, which it successfully did. The DOQ provides a realistic backdrop for the abstract shapes of the Coverage Area boundaries.

Later in the project process, the above mentioned imagery was replaced by an online world imagery layer from the ESRI Resource Center. This was accessed in ArcMap, using the add data from the Resource Center tool in the file drop down menu. This brings you to the ESRI Resource Center webpage (http://resources.esri.com/arcgisdesktop/index.cfm?fa=content&tab=layers) where you can explore the online content. With a click of the sample image, the ArcGISAppLauncher is initiated, automatically bringing in the layer to your map.

4.5 Data Scrubbing and Loading

In all but a few special cases, the data for this project were loaded into the initial eTOD_obstacle geodatabase in their native form. Very little editing of the data had to be performed to make it useful for this project. This is advantageous, as potential clients with limited experience would be hampered by the task of scrubbing project data.

To utilize the existing PLTS tutorial data, the entire tutorial database was exported into a new file geodatabase, the prototype eTOD_obstacle geodatabase. In ArcCatalog, the PLTS SDE database ASPc (a cartographic version of ASPm) was accessed through a connection to SQL Express, and the entire contents were exported to the new file geodatabase. Over one hundred tables, features and relationship classes were loaded. This prototype database was used during the implementation of the Coverage Area tools. Additional data was imported into the database when necessary to successfully generate the Coverage Area boundaries. Eventually, with the completion of the implementation stage, it became clear what the minimum data required. Over time, unneeded features, tables and relationship classes were deleted from the database.

Very few features had to be augmented or edited. The ADHPSurfaceLine feature representing the runway centerlines was just an empty schema, so in an edit session using this feature class, lines were drawn between the threshold points to draw the three runway centerlines for the test case Salinas Airport. The Borders feature, in this case symbolizing US state borders, was renamed from the ReferenceData geodatabase feature US_States. The California border was selected in this feature, and exported to a new shapefile, Territory, which was then loaded into the geodatabase to be used for the Area 1 Coverage Area shape.

The essential eTOD features of ObstacleArea, LineObstacle, PolygonalObstacle and PointObstacle were all empty features with schemas optimized for eTOD. These were provided by ESRI as an update to PLTS. They were installed directly into the project computer at the ESRI office, and then loaded into the eTOD_obstacle geodatabase. Since all obstacle data in the tutorial set were point features, these data were loaded into the PointObstacle feature using the Simple Data Loader tool in ArcCatalog.

4.6 Summary

No GIS solution can function without the appropriate data to model the spatial problems the client is trying to solve. A well conceptualized and designed database provides the foundation for the project implementation functionality. In order to carry out the goals and objectives of this eTOD model solution, a data model had to be established to assess the data needs and how its organization would affect the project functionality. This was carried out in a set of database design steps.

To initiate this process, a conceptual data model for the project was formulated. Here, the fundamental entities needed to accomplish the project goals were identified, and a framework for how to use the data was developed. The discoveries from this phase led to the logical data model phase, where the actual physical design of the geodatabase was formulated. Here, the essential features and attributes were established, and an organization for the database was established. Initial, the full data set from the PLTS tutorial data was used to underpin the prototype models for creating the eTOD Coverage Areas. But through trial and error, this large data set was gleaned into the minimal set of features needed to accomplish the project functions. In most cases, the data was used in its native format, with very few edits or revisions. What finally resulted was a simple, pared down eTOD geodatabase optimized for the functions of this project.

Chapter 5 – Implementation

Once the collection and organization of the requisite data was complete, work could begin on the task of creating useful information to address the project objectives. This chapter concentrates on the efforts to implement the two primary functions of this project – creating the area delineations and assessing the existing obstacle data.

The effectiveness of the entire project rested on the successful compilation of the four required eTOD Coverage Area demarcations. These areas are used to classify the digital terrain and obstacle data for all locations where aircraft can operate. With the adoption of modern technologies like GPS navigation, this means data must be collected for nearly everywhere on earth. To address this monumental task, ICAO elaborated a scheme whereby each nation would be responsible for all digital aeronautical data within their jurisdiction. Requiring data for the entire nation to be of one highest quality standard, as for areas adjacent to airports, would be highly impractical. Therefore, ICAO broke the extent of nationwide data collection into four distinct Coverage Areas. The entire nation is covered by Area 1, while Areas 2-4 focus in on incrementally smaller vicinities around individual airports (Table 9). Each Coverage Area describes specific boundary geometries, and calls for increasingly stringent data quality requirements. These specific details will be discussed in subsections 5.3 to 5.6. Table 9: Coverage Area Definitions

Coverage Area	Description
Area 1	Whole territory of a state (including all airports/heliports)
Area 2	Terminal Control Areas (not exceeding 45 km radius from airport reference point (ARP)), or a 45 km buffer for airports without a TCA, whichever is smaller
Area 3	Specified distances from defined airport surface movement areas
Area 4	Precise areas at the end of runways at airports with precision approach Category II or III operations

5.1 Aeronautical Data Quality

Providing the appropriate data quality for all scales of aircraft operations, from transnational flights to movements at the smallest airport, was ICAO's chief intention in establishing the Coverage Areas. ICAO also meticulously accounted for quality requirements for the great variety of uses of digital terrain and obstacle data, from cockpit data display to proximity warning systems. The eTOD guidelines identify data quality with three essential characteristics: accuracy, integrity, and resolution (Table 10). Data accuracy is defined as "…a degree of conformance between the estimated or measured value and the true value" (ICAO, 2007a, p. 2). Accuracy must be identified with a confidence level – a statistical probability that the true value is within a predetermined interval of the estimate. Data integrity "…is the degree of assurance that an aeronautical data and its value has not been lost or altered since the data origination or authorized amendment" (ICAO, 2007a, p. 12). And finally, resolution represents "…a number of units or digits to which a measured or calculated value is expressed and used" (ICAO, 2007a, p. 14). The mandates also add that terrain data meet minimums for post spacing, the distance between elevation survey points. ICAO established minimum values for accuracy, integrity, and resolution for each of the four Coverage Areas. For example, Area 1 must have a horizontal accuracy of at least 50 meters, while Area 4 must be at least 2.5 meters. These values are listed in accompanying tables for each of the Coverage Area implementation descriptions later in the chapter.

Table 10: Data Quality Requirements

Requirement	Description of unit or designation
Accuracy	A measurement, in meters, of the maximum allowable distance between the surveyed location/height of the feature and the true position/height of the feature.
Integrity	Critical - If data is corrupted, high probability of severe risk to safe operation of aircraft. Integrity level $\geq 10^{-8}$ Essential - If data is corrupted, low probability of severe risk to safe operation of aircraft. Integrity level $\geq 10^{-5}$ Routine - If data is corrupted, very low probability of severe risk to safe operation of aircraft. Integrity level $\geq 10^{-3}$ 10^{-x} indicates the probability of data being unintentionally revised since the data set was created.
Resolution	Minimum units, in meters, required to make measurements. The use of more decimal places means higher resolution.
Confidence Level	The probability that data errors are within specified intervals or limits, expressed as a percentage (90%, 95%, or 99%).
Post Spacing	The distance between adjacent elevation points, expressed in arc seconds and its meter equivalent.

5.2 Coverage Area Toolbox

The methods and procedures assembled for creating the four eTOD Coverage Areas were organized into a single ArcToolbox, the eTOD Coverage Area Toolbox (Figure 5.1). Placed inside this custom toolbox were four toolsets designed to formulate each of the Coverage Areas boundaries. Models were devised for each of these toolsets, customized to assemble each Coverage Area with its specific requirements. The toolsets were arranged as subsets of one toolbox so that users need only find, add, and employ one toolbox to create all four areas. Since every airport has a unique combination of appropriate Coverage Areas, this organization allows the user to conveniently choose the suitable Coverage Areas for their selected airport. Having all the models in one toolbox also offered advantages in organizing help and procedural documentation for the project.

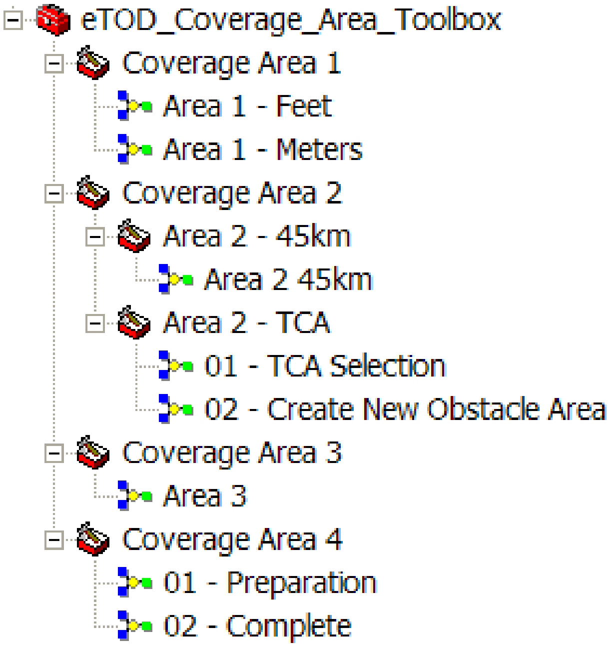


Figure 5.1: eTOD Coverage Area Toolbox

Using a toolbox and toolset organization scheme maximized the benefits of exploiting the ArcGIS documentation management tools. In ArcCatalog, the geoprocessing stylesheet in the metadata toolbar was used to create an overview help document for the entire toolbox. This documentation is accessed in the ArcMap mapping session by clicking help in the toolbox pull down menu, which opens up a web browser page. This page outlines the step-by-step process of creating these coverage boundaries. In addition, the toolbox can be further explored in the ArcCatalog metadata tab. Here, more information is provided about the toolbox, including contact details for further assistance, and a discussion of use constraints. While providing this information in a conventional Microsoft Word user manual document was considered early on, consolidating all directions and information in the automatic help files kept these important documents centrally located and easily accessible.

5.3 Coverage Area Model Basics

The first model to be developed was the Area 1 model, as this was the easiest Coverage Area to generate. Through a lengthy process of trial and error, a sequence of tasks began to emerge that best produced the intended results. A framework, or prototypical model, eventually materialized which would be become the template for the remaining models. The prototype model can be said to have four principal elements: selection, analysis, obstacle selection, and create new obstacle area (Figure 5.2). With a few exceptions, most models in this project follow this configuration. In this way, only the analysis section needs to be altered to create the desired results. The other three sequences of steps function similarly for each model.

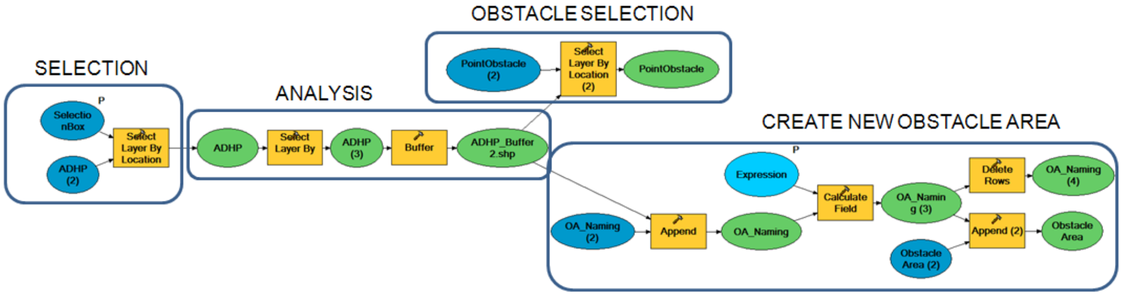


Figure 5.2: Model Organization

One of the most difficult tasks for a beginning user of GIS is to select the correct input data for analysis. This was especially critical in this project, as the eTOD delineations must be exactly generated from the stated geographic features. Many techniques for selection were tried, from using the select by attribute tool, to the manual selection of pointing to the desired data on the screen. For a new GIS user, however, this can be complicated. Setting the selectable layers and the correct selection method can be confusing. And with the complex and overlapping features of aeronautical data, selecting precisely the right feature in this maze is almost impossible. To address this challenge, a technique of using a user drawn bounding box to select the data was devised.

Because of the complexity of aeronautical data, with its complex subtype and domain setups, just choosing a feature may not be enough. The user needs to choose the right geographic feature, with the right attributes and domains. Instead of leaving this up to the user to do correctly, an automated system was devised to assist the user in selecting the right data. Using a select layer by location or select layer by attribute tool, the user must still give the input data to select, and a selecting feature to isolate the correct features, or a SQL expression to pick the features with the right attribute. To automate these required steps, an empty selection box polygon feature was first created to use as a template that allows the user to interactively draw a selection box around their desired features. By using this as the selecting feature, changing its data type to a feature set, and making it a model parameter, it alters the input procedure to an interactive method of drawing a polygon around the desired features. Clicking the add feature pointer button, the user draws a polygon around the feature of choice, based on the airport or area they want to analyze (Figure 5.3). This user drawn box then becomes a temporary selection feature to isolate the data located within. In this way, the user need only know the location of their airport or area, not the specific data that needs to be selected for the model to work. Once this task is mastered, it is repeated in every model.

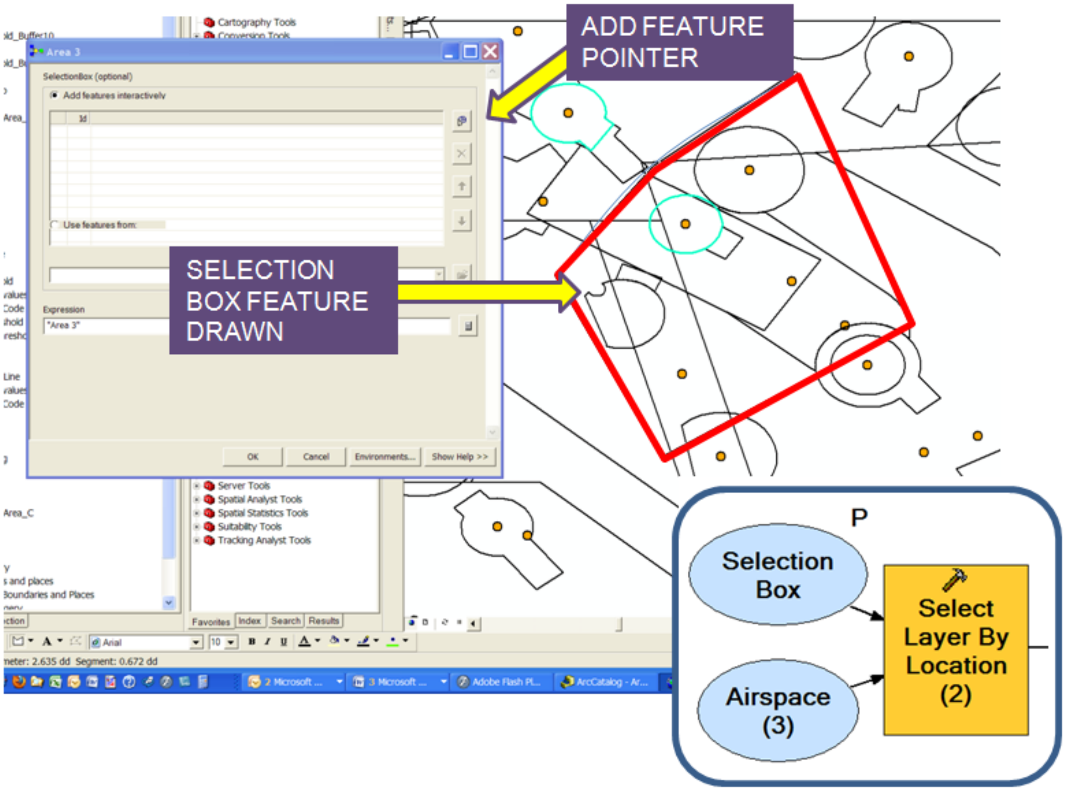


Figure 5.3: Selection Methodology

One of the primary goals of this project was to assess a client's existing data to compare it to eTOD standards of quality. For every Coverage Area toolset, the appropriate obstacles had to be selected. This was accomplished in the same way for every model (Figure 5.4). After the shape had been generated for the respective Coverage Area, the model used this shape as a selecting feature to isolate the obstacles within. This was done before the assembled shape was appended to the obstacle_area feature class, so that only the individual shape created was used to select obstacles. If this step were taken later in the model, all obstacle area features in the feature set would be used to select the obstacles, creating a widespread, unfocused obstacle selection set.

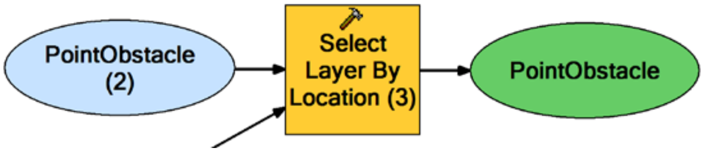


Figure 5.4: Obstacle Selection Tools

Another primary goal of this project was to create the eTOD Coverage Areas. For each model, this was done by specific analysis, which will be discussed in the following Coverage Area discussions. But once an obstacle area was generated, it needed to be saved for later use or analysis. The obstacle_area attribute, "type_code" uses domains to reflect what obstacle area type it is, such as Area 2. Using model builder, a method for the user to interactively select the correct code was not successfully implemented. Even if this were successfully done, there still would be no way for the user to identify the Coverage Area quickly by name, or by other user defined distinguishing characteristic. Thus, a method was created to allow the user to type in a name or code to distinguish their specific obstacle area.

To enable a naming function, a sequence of tools was assembled (Figure 5.5). First, the derived obstacle area shape was appended to a temporary polygon feature called OA_Naming, which is identical to the obstacle_feature. Using the calculate field tool, a variable was set for this tool that allows the user to type in their desired descriptor in a dialogue box called expression, which adds this text to the field “Name.” Then, this temporary feature was appended to the final obstacle_area feature class, carrying along the text in the “Name” column. At the same time, the temporary OA_Naming feature was deleted, so that an empty OA_Naming feature class could be used for the next iteration. If this step was not added, the iteratively added Coverage Area shapes would replace those already in the obstacle_area table.

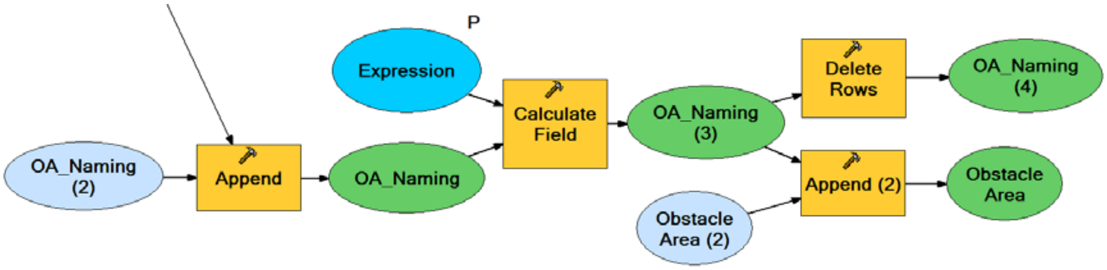


Figure 5.5: Create New Obstacle Area Tools

Using these three repeated sequences of tools simplified the process of creating all the required Coverage Area shapes, and provided consistency to the user in selecting input data and adding a descriptor name to their newly created obstacle area. In the next sections, the methods of assembling the analysis tools to generate the specific configurations of the Coverage Areas are outlined.

5.4 Coverage Area 1

The most generalized and comprehensive of the eTOD Coverage Areas is Area 1, defined as “…the whole territory of a State, including aerodromes/heliports” (ICAO, 2007a, p. 22). As such, the Area1 delineation is the same as the territorial boundary. Within this boundary, terrain and obstacle data must be obtained with the minimal requirements outlined in Table 11. All applicable terrain data must be collected for this area, while only obstacles taller than 100 meters within the boundary must selected. The user must be able select the suitable territorial boundary, and generate a new Coverage Area boundary from this selection. In addition, obstacles over 100 meters high must be selected within this new Coverage Area. These tasks were accomplished with the Area 1 Toolbox.

Table 11. Area 1 Data Requirements

Obstacle	Requirements	Terrain	Requirements
Horizontal Accuracy	50.0 m	Horizontal Accuracy	50.0 m
Data Integrity	Routine (10^{-3})	Data Integrity	Routine (10^{-3})
Vertical Accuracy	30.0 m	Vertical Accuracy	30.0 m
Vertical Resolution	1.0 m	Vertical Resolution	1.0 m
Confidence Level (1σ)	90%	Confidence Level	90%
Maintenance Period	As Required	Database Post Spacing	3 arc sec (100 m)

The Area 1 Toolbox was created to form the area 1 Coverage Area, and then use this new boundary to isolate the obstacle data. To accomplish these tasks, an Area 1 Model was designed. The diagram below (Figure 5.6) shows the steps and tools used within the model. The Area 1 model has a slight revision from the standard organization for the Coverage Area models. Since there will only be one territory boundary to chose, this selection is automatically made for the user in the configuration of the append tool. The remaining three steps – analysis, new obstacle area creation, and obstacle selection – follow the standard outline. This is the prototypical model on which all other areas were built. There is no specific analysis, apart from the standard append functions. The obstacle selection step, however, was specially configured for this model.

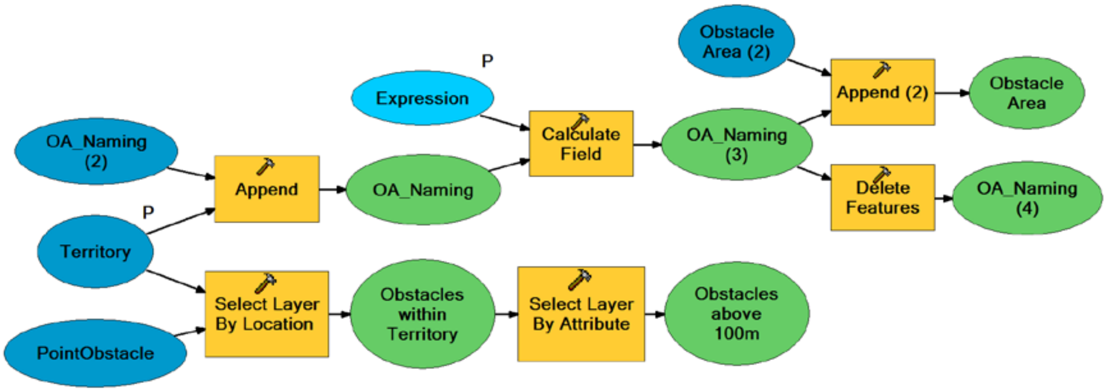


Figure 5.6: Area 1 Model

Unlike the other models, the Area 1 model selects only those obstacles within the Area 1 boundary that are 100 meters or taller. While the eTOD mandates use metric measurements, some existing data, like data for this project case study, record obstacle heights in feet. An optional model was created (Area 1 – Feet) that selects the obstacles with an equivalent foot measurement (328 feet). This was accomplished by setting an optional expression ("Height_Val" >328) in the select by attribute tool. The remaining

Coverage Areas 2 through 4 concentrate on specific airports. These areas have much more complex geometries, and unlike the single territory feature in this model, are built out of a collection of varying and sometimes overlapping features.

5.5 Coverage Area 2

Of the three remaining Coverage Areas, area 2 is the most difficult to assemble. In fact, during the building of this project, Coverage Area 2 was revised to an even more complex geometry which will be discussed in the final chapter. This area is designated by the smaller of two possible boundaries: a terminal control area, or an area covering a 45 kilometer radius around the airport. Explaining a few aeronautical terms associated with this Coverage Area will help clarify the reasons why the International Civil Aviation Organization (ICAO) formulated this area in such a manner.

ICAO institutes the terminology for naming and describing aeronautical information. Two important terms in this lexicon are essential to definition of Coverage Area 2: terminal control area (TCA) and airport reference point (ARP). A terminal control area, also called a terminal maneuvering area (TMA - a British derivation of the term), is a region of managed airspace around a major airport, configured to safeguard takeoffs and landings. These critical areas usually occur at airway intersections so that enroute traffic and airport traffic are carefully spaced, separated, and controlled (Eckland, 2007). A TCA is one of many classifications of controlled airspace, which occurs where all flights, both Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) operations, are monitored and directed by an air traffic control service. The airspace is distinctively configured for every terminal control area, but is commonly a container of space starting at the airport surface and rising to 10,000 meters mean sea level (U.S. Department of Transportation - Federal Aviation Administration, 2008). To establish such airspace volumes and other assorted airport boundaries, an airport's geographic center point must often be established. Such a point is called an airport reference point (ARP), a designated geometric center of all "useable runway surfaces" (U.S. Department of Transportation - Federal Aviation Administration, 2008, p. PCG A8). Both terminal control areas and airport reference points are used to create Coverage Area 2.

A Coverage Area 2 boundary must be generated for every airport/heliport in a territory. For those possessing a terminal control area, the TCA boundary is used for the Area 2 delineation. However, if an area covered by a 45km radius circle (centered on the ARP) is smaller, this circular boundary is employed for Area 2. The 45 km radius circle is always used for airports without terminal control (ICAO, 2007a). Whenever the 45 km circle is used, areas within the circle designated as restricted areas must be excluded. A diagram from the eTOD guidelines (Figure 5.7) superimposes the TCA, 45 km circle, and Coverage Area 1 designations. The dotted circle shows the 45 km radius boundary centered on the airport reference point. The white area represents the terminal control area (or TMA, as in this diagram). In this example, the TMA would be chosen as Coverage Area 2, as it has the smallest area. In either case, airspace where flight operations are prohibited (hatched area) must be eliminated from the final Coverage Area. The shaded area beyond Coverage Area 2 denotes Area 1 – the entire territory. Note the side view below the diagram displaying the obstacle collection surface. This profile introduces an important compromise made in determining the final functionality of the Area 2 delineations.

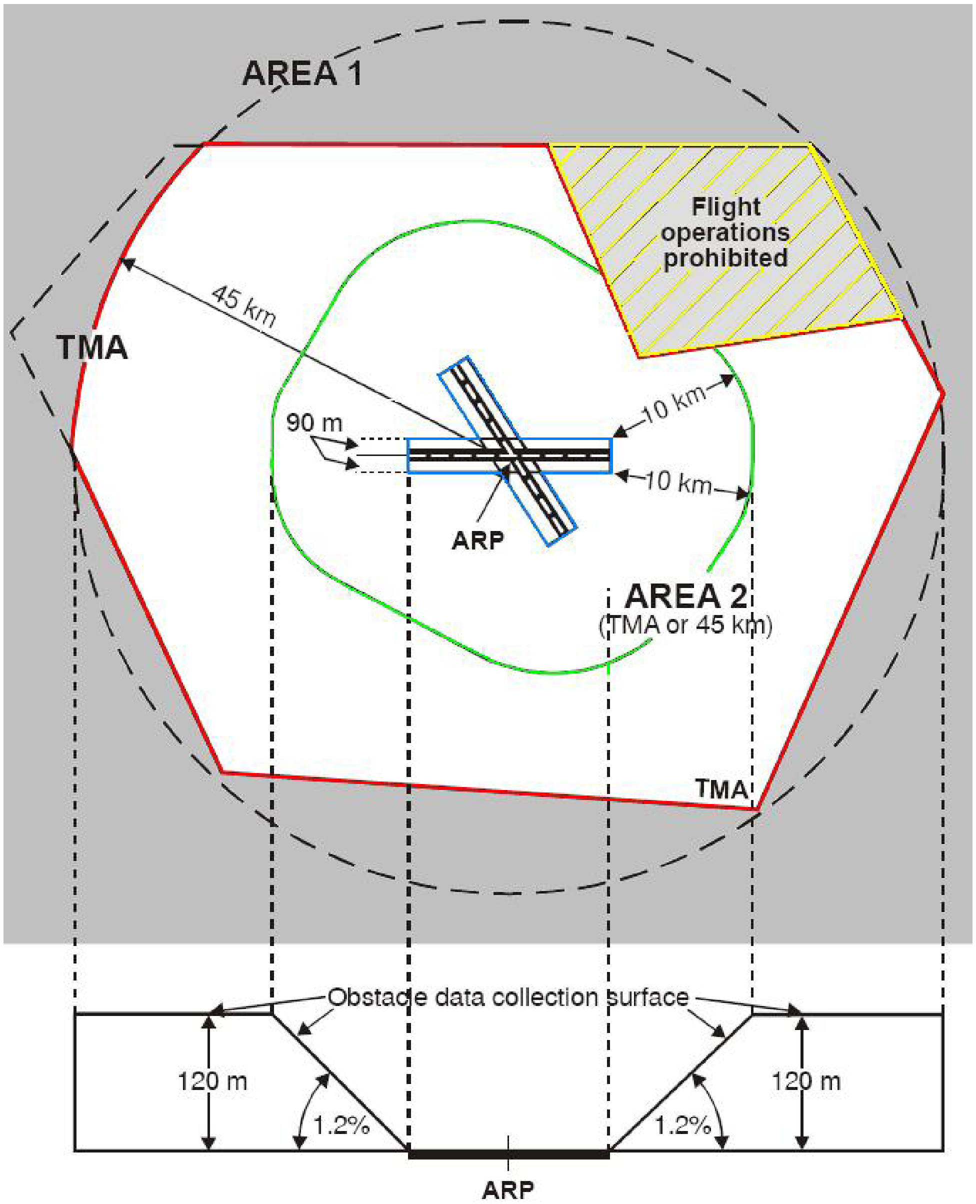


Figure 5.7: Coverage Area 2 (Source: ICAO, 2007)

Unlike the other Coverage Areas Area 2 is best described as a three-dimensional surface, a cone surrounding the airport area. As shown in Figure 5.7, the origin of the cone is at the runway edge, and extends at a 1.2% slope until reaching a 120 meter high (from the lowest runway elevation) surface. Any obstacles penetrating this undulating surface within the boundaries of Area 2 must be included in the eTOD set. This three-dimensional surface cannot be created without using the 3D Analyst extension and a higher license level of ArcGIS. Since this would violate ESRI's stipulations for this project, it was decided that creating a two-dimensional boundary would be an adequate first step. Establishing this boundary still provides a helpful tool in planning for Area 2 data acquisition. These data must comply with the minimum requirements shown in Table 12. When compared with Coverage Area 1, these requirements are much stricter.

For example, horizontal accuracy jumps from 50.0 meters to 5.0 meters. Coverage Areas 3 and 4 have even stricter quality requirements.

Table 12: Area 2 Data Requirements

Obstacle	**Requirements**	**Terrain**	**Requirements**
Horizontal Accuracy	5.0 m	Horizontal Accuracy	5.0 m
Data Integrity	Essential (10^{-5})	Data Integrity	Essential (10^{-5})
Vertical Accuracy	3.0 m	Vertical Accuracy	3.0 m
Vertical Resolution	0.1 m	Vertical Resolution	0.1 m
Confidence Level (1σ)	90%	Confidence Level	90%
Maintenance Period	As Required	Database Post Spacing	1.0 arc sec (30 m)

The methodology for creating the Area 2 boundaries was organized into a Coverage Area 2 toolset. Within this toolset, two subset toolsets were developed for each Area 2 option: Area 2 – TCA and Area 2 – 45km (Figure 5.8). A user must first determine if their airport of choice has a TCA associated with it. If so, they must run all the models in both toolsets, and compare the Shape_area field for both generated obstacle areas, making their choice from the smaller of the two areas. If the airport does not have a TCA, only the Area 2 – 45km model need be used.

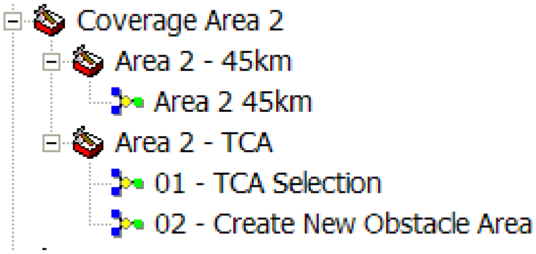


Figure 5.8: Coverage Area 2 Toolsets

The Area – 2 TCA toolset contains the procedures for formulating an airport’s terminal control area into an Area 2 boundary. This toolset does not follow the standard project model configuration, but instead was subdivided into two models: TCA Selection, and Create New Obstacle Area. The first model, 01 - TCA Selection (Figure 5.9), was designed to help the user sift through the complex and overlapping layers of the airspace feature class, and identify only those that are terminal control areas within their territory. Running this model creates a selection set of TCAs which are highlighted in cyan on the ArcMap screen. This concludes the first step in creating the area 2 TCA coverage.

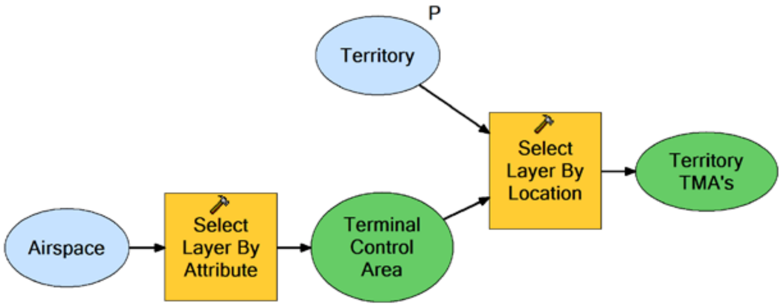


Figure 5.9: Model 01 -TCA Selection

The second model, 02 - Create New Obstacle Area (Figure 5.10), takes the user selected TCA and converts it into a new obstacle area feature. This model follows the prototypical model design for this project. The user initiates this model by drawing the temporary selection box around the TCA that was highlighted by running the first model. The remaining steps then carry out the predictable tasks, with no intervening analysis. This is because the shape of TCA is used as the boundary for Coverage Area 2, without any revision. The model similarly selects obstacles within this boundary without any further analysis of obstacle heights, etc. While this model is specifically for airports with TCAs, a majority of airports will not have an associated terminal control area. For these conditions, a second Area 2 toolset was designed.

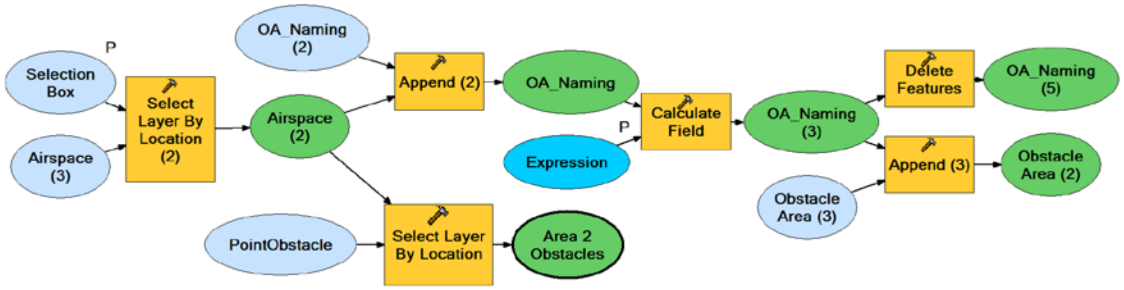


Figure 5.10: Model -02- Create New Obstacle Area

The Area 2 – 45 km toolset was formulated to create the second type of Coverage Area 2. In most cases, a user will utilize the model located within this toolset to generate the more common 45 km Coverage Area. The Area 2 – 45km model (Figure 5.11) is configured from the prototype model layout. In the selection step, the user draws a selection box around the center point (ADHP) of their airport and the select layer by location tools then selects this point. The ADHP feature class has two domains for the attribute Type_Code: AD for Aerodrome and HP for Heliport. The select layer by attribute tool selects domain AD. With this correct point selected, the buffer tool then creates the 45 km circle which is used for the shape to add to the obstacle_area feature class. Whereas Areas 1 and 2 demarcate airspace at airports, areas 3 and 4 demarcate the surface areas around airports.

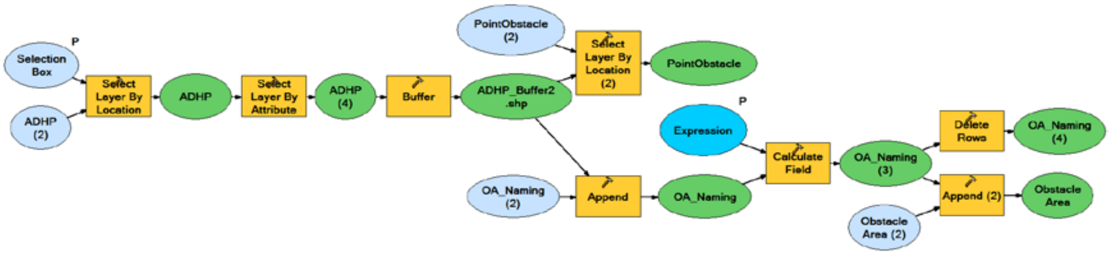


Figure 5.11: Model - Area 2 45km

5.6 Coverage Area 3

Coverage Area 3 defines the spaces around airport surfaces where aircraft can maneuver. ETOD uses an existing boundary established by ICAO that distinguishes areas within a certain distance from aircraft movement surfaces (e.g., runways and taxiways). ETOD adopted this shape because it accounts for the clearance requirements of moving aircraft and provides extra space around runways for takeoff and landing contingencies (ICAO, 2007a). ICAO, however, set unique eTOD data quality rules within these replicated borders. On movement surfaces other than runways, like taxiways, a 50 meter buffer is established from the edge of the pavement (Figure 5.12). For runways, a 90 meter buffer is set from both sides of the runway centerline. These two buffers are merged into a continuous Coverage Area 3, as shown by the green shading in the graphic.

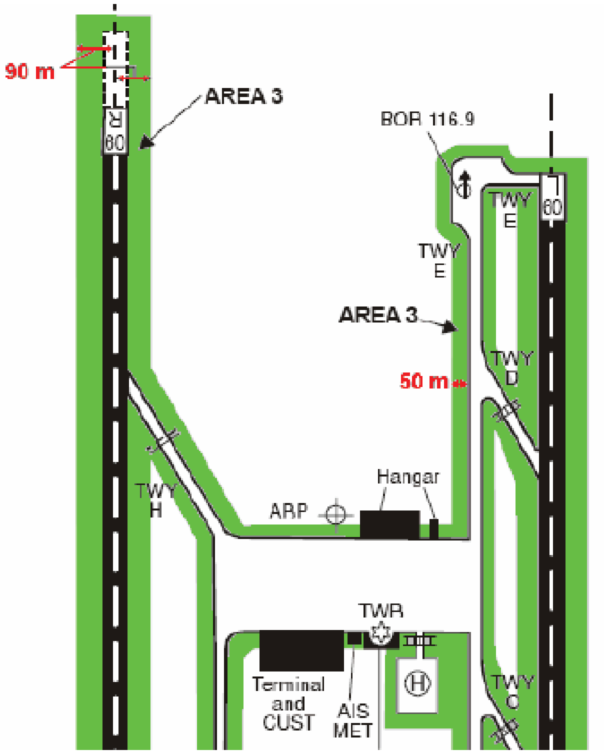


Figure 5.12: Coverage Area 3 (Source: ICAO, 2007)

The buffered area surrounding aircraft movement surfaces establishes a zone of data acquisition for coverage Area 3. Unlike in Area 2, the capture of vertical objects and terrain in Area 3 is straightforward. Any objects and terrain within the horizontal region of area 3 that are taller than 0.5 meters must be captured (Figure 5.13).

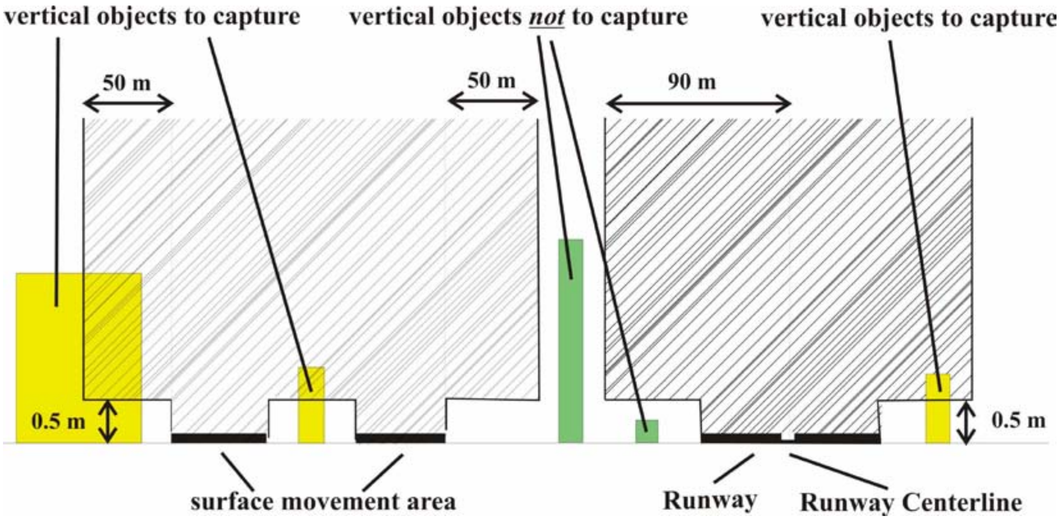


Figure 5.13: Area 3 Obstacle Data Vertical Extent (Source: ICAO, 2007)

While this is an established airport mapping convention, ICAO sets specifics mandates for eTOD data quality, as shown in Table 13. Airport structures are not considered obstacle data and have their own reporting requirements beyond the scope of eTOD. However, control towers must always be captured in this Coverage Area 3, regardless of their location within the delineation zone.

Table 13: Area 3 Data Requirements

Obstacle	Requirements	Terrain	Requirements
Horizontal Accuracy	0.5 m	Horizontal Accuracy	0.5 m
Data Integrity	Essential (10^{-5})	Data Integrity	Essential (10^{-5})
Vertical Accuracy	0.5 m	Vertical Accuracy	0.5 m
Vertical Resolution	0.01 m	Vertical Resolution	0.01 m
Confidence Level (1σ)	90%	Confidence Level	95%
Maintenance Period	As Required	Database Post Spacing	20 m

With the Coverage Area 3 parameters defined, a methodology to generate the area boundary was established. To accomplish this, the user needed only to run one model in the Coverage Area 3 toolset – the Area 3 model (Figure 5.14). Once again, this model

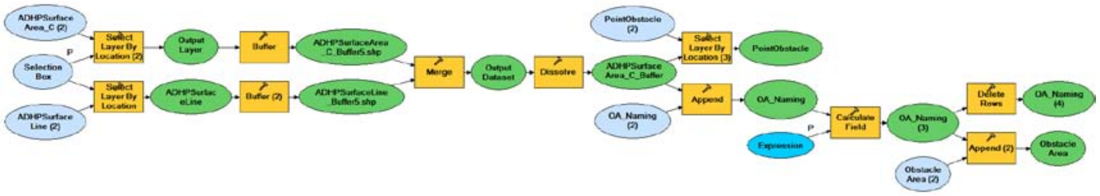
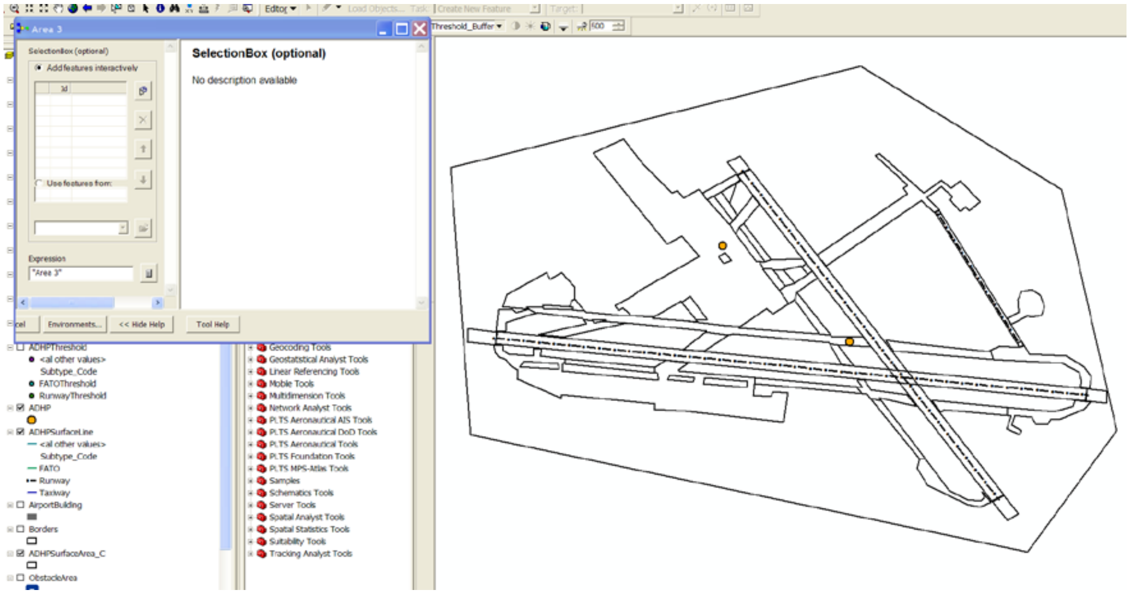


Figure 5.14: Model - Area 3

followed the prototype for all models in this toolbox, with specific changes to the selection and analysis steps. The interactive selection box method is especially helpful for this model. Since there are two types of buffers utilized in this model, a 90 meter buffer around the runway centerline, and a 50 meter buffer from pavement edges, the user needs to select all of these features for their selected airport. Drawing a large selection box around the entire airport allows the user to simultaneously select all the required data for the analysis (Figure 5.15). The buffer tools then use these selected data to create initial buffers around these features – 90 meters around the runway centerline, and 50 meters around the surface area features (e.g., taxiways). These buffers are then merged into one, with the overlapping and intersecting polygons dissolved into one seamless obstacle area.



SelectionBox (optional)

No description available

Expression: "Area 3"

Figure 5.15: Area 3 Selection Box Task

5.7 Coverage Area 4

Like Area 3, eTOD Coverage Area 4 focuses on the surface of the airport. However, Coverage Area 4 applies only to very specific types of airports – facilities with CAT II/III operations. Category (CAT) II/III airports provide advanced equipment and procedures for instrument landings. Instrument landing systems guide aircraft towards runways during conditions of limited visibility, in which a pilot cannot see the runway from certain defined distances. An airport-based radio system broadcasts precise signals that supply the pilot with a defined lateral and vertical path towards the runway. The categories (I thru III) designate the minimal visibility conditions for safe operations. For example, a CAT II system allows landings where the ceiling (the height of lowest clouds) is 100 feet, and visibility of the runway or approach lights is within 1200 feet. CAT III operations are further defined, with a CAT IIIC facility having no restrictions (Department of Defense and Department of Transportation, 2001). Since these facilities allow landings during conditions of limited or no visibility, accurate information about the terrain below is essential to performing safe landings.

The configuration of Coverage Area 4 is based on the minimal requirements for safe instrument landings. Aircraft with instrument landing capabilities use radar altimeters to detect their elevation during descent. A critical zone for using these devices is the area covered in the last few minutes of the approach until the final touchdown. Coverage Area 4 represents this zone, which eTOD establishes as a rectangular area extending 900 meters from the runway threshold (Figure 5.16). The runway threshold is the start of the portion of the runway used for landings. The rectangle width is 120 meters, centered on an extension of the runway centerline (ICAO, 2007a). Obviously, there can be no obstacles within this zone, so Coverage Area 4 only establishes data quality for terrain data (Table 14).

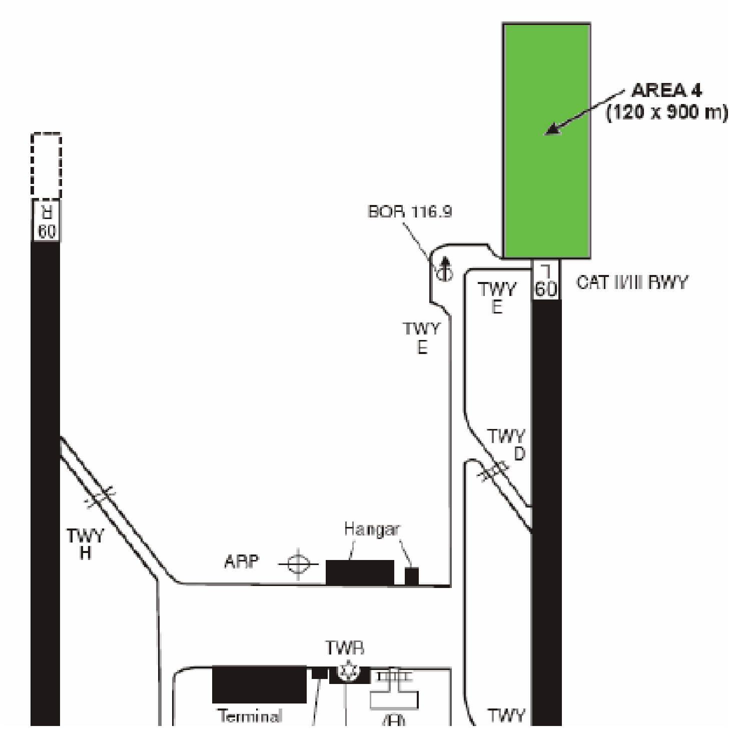


Figure 5.16: Coverage Area 4 (Source: ICAO, 2007)

Table 14: Area 4 Data Requirements

Terrain	Requirements
Horizontal Accuracy	2.5 m
Data Integrity	Essential (10^{-5})
Vertical Accuracy	1.0 m
Vertical Resolution	0.1 m
Confidence Level	90%
Terrain Publication Timeliness	As Required
Terrain Database Post Spacing	0.3 arc second (10 m)

To generate the Coverage Area 4 boundary, the Coverage Area 4 toolset was created. This toolset consists of two models: the 01- Preparation model, and the 02- Complete model. These models will be the least used of all the models in the eTOD Coverage Area toolbox, as Area 4 airports (CAT II/III operations) are the least common. Despite its infrequency and relatively simple geometry, Coverage Area 4 must be constructed with very precise parameters. The simple rectangle shape must be accurately centered on an extension of the runway centerline, and start exactly at the runway threshold. The steps and tools for this toolset were carefully selected and arranged to conform to these strict standards.

After many experiments with multiple tools, and consideration of the functional limitations of ArcView, the optimal solution for this toolset emerged as a series of steps using models and ArcMap editing functions. The first step was identifying the essential components to begin the process. The user needs to start with the threshold point for the instrument landing end of their selected runway, which may only be one direction of the runway. By initiating the first model, 01- Preparation, the user draws a box around the threshold point (ADHPThreshold feature) they desire, from which a 900 meter buffer circle is created and displayed in ArcMap. With a buffer methodology complete, editing functions were then devised to complete the creation of this Coverage Area.

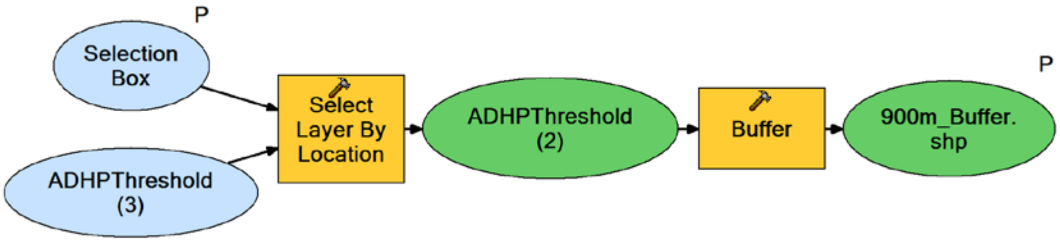


Figure 5.17: Model – 01- Preparation

Having the user enter an edit session and actually draw components of this area was the most effective way to accurately anchor the Coverage Area rectangle. The user draws a centerline for the rectangle which acts as an extension of the runway centerline, ensuring that the Coverage Area is parallel to the runway. In the ESRI PLTS – Aeronautical solution, advanced functions using azimuth calculations and directions are efficiently used to create this surface, but these functions are not available in ArcView. Moreover, many useful editing tools, like offsetting lines or creating parallel lines, are also not available. In addition, many useful editing tools, such as offsetting, use map units for distance. Since ESRI requested that the solution work without using projections, map units could not be used, as map units for any unprojected map are in decimal degrees. However, with the 900 meter buffer circle created in the first model, a vertex could be established at the implied intersection of the runway centerline and the buffer circle. In an edit session, the user begins by creating a new feature – a line –with the target Area4_Line feature class. The user begins by selecting the intersection tool, hovering over the runway centerline, and then hovering over the 900 meter buffer circle opposite the threshold point. This automatically inserts a vertex at the implied intersection (Figure 5.18). The user then switches to the sketch tool and draws a line from this vertex to the nearest threshold point, creating a 900 meter-long centerline for the Coverage Area. Having established this line, the user moves to the next step of initiating the Complete Tool.

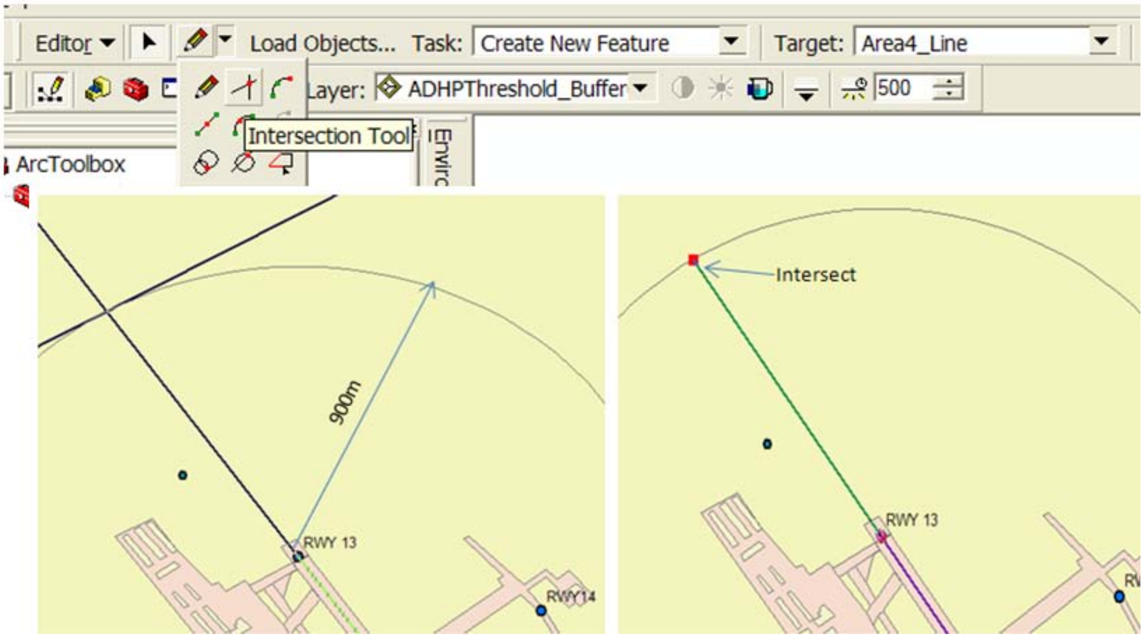

Task: Create New Feature
Target: Area4_Line
Layer: ADHPThreshold_Buffer
500

Figure 5.18: Using Intersection Tool

Having created an anchor centerline for the eventual Area 4 coverage shape, the user then simply runs the 02 - Complete model (Figure 5.19) to finish the analysis, create a new obstacle area, and obstacle selection tasks. The buffer tool utilizes the user created centerline to make a 60 meter buffer shape, thus establishing the required 900 meter x

120 meter rectangular shape. As in all the models, the obstacles within this new Coverage Area are simultaneously selected for assessment.

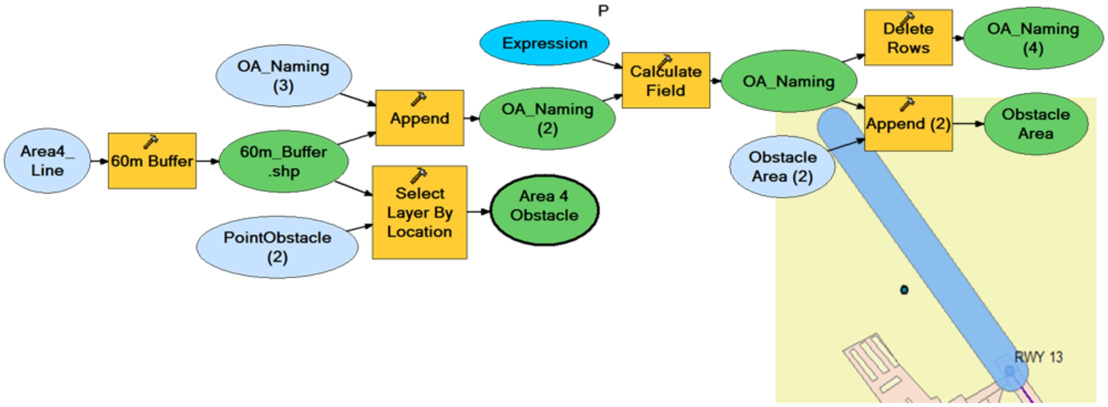
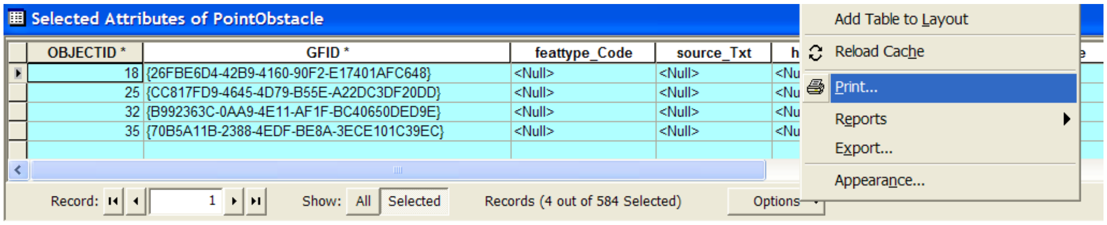


Figure 5.19: Model – 02 - Complete

5.8 Obstacle Assessment

Using any of the models described above, a user can easily and automatically isolate their existing obstacle data for assessment and comparison to the eTOD standards of quality for their representative Coverage Area. This project proposes three methods to report on the selected obstacles: printing to an Adobe PDF file, exporting to an Excel spreadsheet, or utilizing a layout view template to be used in ArcMap.

The last step of each Coverage Area model creates a selection set of obstacles that are located within the newly generated Coverage Area created by the model. From here, the user can simply open the obstacle feature attribute table, click show selected, and get the list of obstacles. If they want to export this data, they have several options. They can print the attribute table to an Adobe PDF file (Figure 5.20), which nicely formats the columns and rows into a readable table (Figure 5.21).



Selected Attributes of PointObstacle

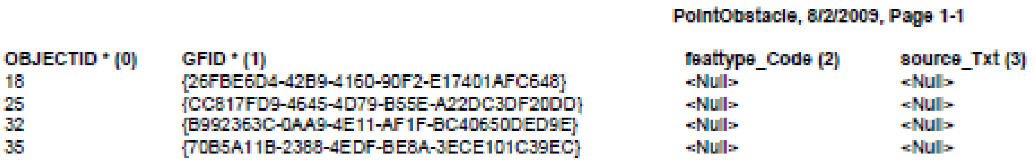
OBJECTID *	GFID *	feattype_Code	source_Txt	h
18	{26FBE6D4-42B9-4160-90F2-E17401AFC648}	<Null>	<Null>	<Nu
25	{CC817FD9-4645-4D79-B55E-A22DC3DF20DD}	<Null>	<Null>	<Nu
32	{B992363C-0AA9-4E11-AF1F-BC40650DED9E}	<Null>	<Null>	<Nu
35	{70B5A11B-2388-4EDF-BE8A-3ECE101C39EC}	<Null>	<Null>	<Nu

Record: 1

Show: All Selected

Records (4 out of 584 Selected)

Figure 5.20: Printing Selected Attributes with Adobe PDF

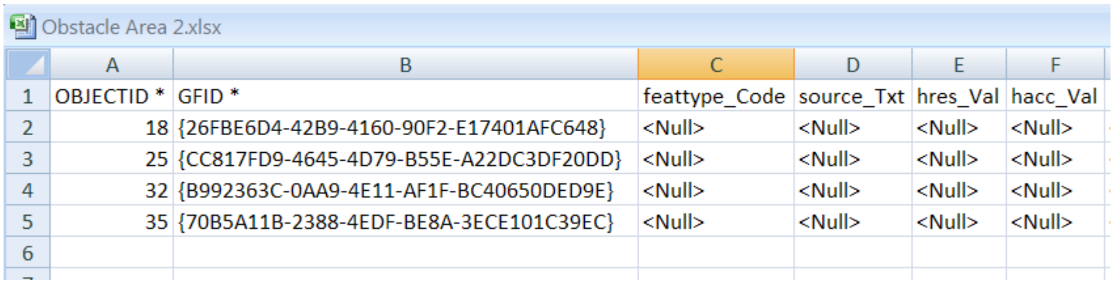


PointObstacle, 8/2/2009, Page 1-1

OBJECTID * (0)	GFID * (1)	feattype_Code (2)	source_Txt (3)
18	{26FBE6D4-42B9-4160-90F2-E17401AFC648}	<Null>	<Null>
25	{CC817FD9-4645-4D79-B55E-A22DC3DF20DD}	<Null>	<Null>
32	{B992363C-0AA9-4E11-AF1F-BC40650DED9E}	<Null>	<Null>
35	{70B5A11B-2388-4EDF-BE8A-3ECE101C39EC}	<Null>	<Null>

Figure 5.21: Adobe PDF Formatting

For more control in formatting the data report, they can copy the data to an excel spreadsheet for customization. With the selected attribute table open, the user merely highlights the selected rows, copies them, and pastes them into an Excel spreadsheet (Figure 5.22). The spreadsheet automatically delimits the columns for each attribute, making it easy to make an easy to use customizable report.

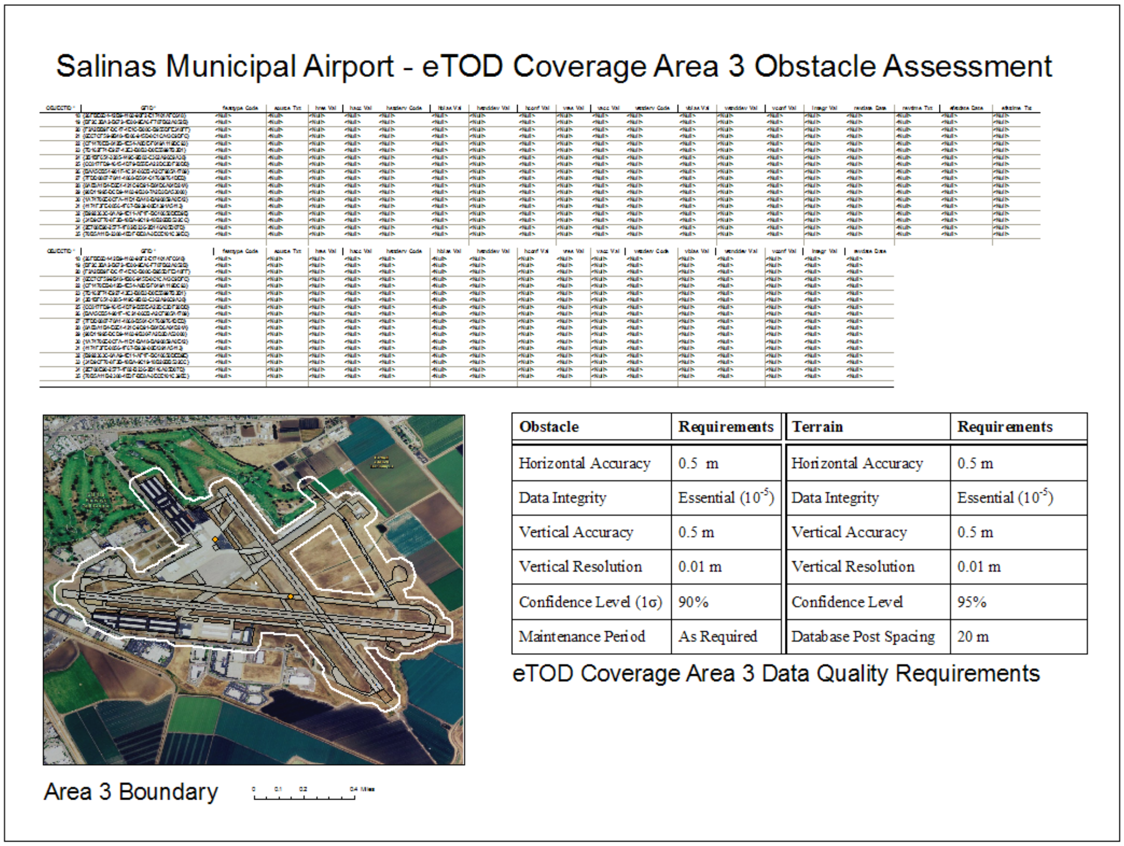


Obstacle Area 2.xlsx

	A	B	C	D	E	F
1	OBJECTID *	GFID *	feattype_Code	source_Txt	hres_Val	hacc_Val
2	18	{26FBE6D4-42B9-4160-90F2-E17401AFC648}	<Null>	<Null>	<Null>	<Null>
3	25	{CC817FD9-4645-4D79-B55E-A22DC3DF20DD}	<Null>	<Null>	<Null>	<Null>
4	32	{B992363C-0AA9-4E11-AF1F-BC40650DED9E}	<Null>	<Null>	<Null>	<Null>
5	35	{70B5A11B-2388-4EDF-BE8A-3ECE101C39EC}	<Null>	<Null>	<Null>	<Null>
6						

Figure 5.22: Report in Excel Spreadsheet

If the user prefers a more map-like layout for their obstacle data report, a layout template has been created for each Coverage Area type. By using the mxd files provided for each Coverage Area, the user just switches to layout view to see the report layout (Figure 5.23). Because the obstacle feature classes have so many attributes to cover the required eTOD information, the report has been optimized to include the selected attribute table at 10 point font, in two sections. With the obstacle attribute table open, the user clicks *options*, and clicks *add table to layout*. Because the table is so long, it should be copied in the layout view, pasted below, and minimized to show a layered sequence of all the attributes. In this configuration, the report must have a minimum page size of 18” x 24.” Included in the layout is a table displaying the eTOD requirements of the Coverage Area for data quality comparison. In addition, a map showing the Area 4 boundary is added to give the report a visual representation of the Coverage Area, and to show the geographic extent of the area where additional data must be acquired to comply with the eTOD requirements.



Salinas Municipal Airport - eTOD Coverage Area 3 Obstacle Assessment

Obstacle	Requirements	Terrain	Requirements
Horizontal Accuracy	0.5 m	Horizontal Accuracy	0.5 m
Data Integrity	Essential (10^{-5})	Data Integrity	Essential (10^{-5})
Vertical Accuracy	0.5 m	Vertical Accuracy	0.5 m
Vertical Resolution	0.01 m	Vertical Resolution	0.01 m
Confidence Level (1σ)	90%	Confidence Level	95%
Maintenance Period	As Required	Database Post Spacing	20 m

eTOD Coverage Area 3 Data Quality Requirements

Area 3 Boundary

Figure 5.23: ArcMap Layout View Report

5.9 eTOD Model Toolkit

All of the tools, data, and requisite files needed to accomplish the project goals were included in the eTOD Model Toolkit DVD supplied to the client. They then determined the best method for their potential customers to access these tools and processes. The toolkit was designed for the flexible use of the custom eTOD databases and models, and consists of the file geodatabases, the eTOD Coverage Area toolbox ArcMap mxd files, and layer files.

Two file geodatabases were supplied for the project: the eTOD_obstacle database, and the eTOD_schema database. The eTOD_obstacle database included all the required feature sets to run the models, as well as the contextual data for the reporting function. The database included the data for the project test case – the southwest United States and the Salinas Municipal Airport. A user can utilize this database for training, becoming familiar with the tools and methodologies without having to load their own data. In contrast, the eTOD_schema database is an empty database with only the schema provided. No data was loaded into this database so that clients can load their own data. Using the Simple Data Loader dialogue box in ArcCatalog, the user can load their data into the features located in the eTOD_schema database, allowing them to reconcile conflicts between attributes and prepare their data for an eventual eTOD submittal.

Located within both geodatabases is the eTOD Coverage Area Toolbox, which includes the four Coverage Area toolsets and their respective models.

The toolkit also included ArcMap mxd files and layer files to help the beginning user quickly access the data in ArcMap and have the tools available ready at hand. Each mxd file had all the data added to the table of contents, and the features were symbolized to reduce the amount of decisions a first time user has to make, facilitating the best views for the overlapping data. The project test case data was used in these mxd files to show what a typical map would look like. The users add their data to this map, or create an empty template to start their own project. This is what the layer files are for. They contain all the symbology for the data and point to the correct feature classes. This way, if the user loads their data into the empty schema, they can still bring in the layer files and not have to take the time to symbolize their own data, making it consistent with the sample data. In addition, the toolkit includes four mxd files representing the four Coverage Areas. These mxd files include the layout schemas already set for an 18” x24” obstacle assessment report.

With the completion of the geodatabases, the Coverage Area model processes, and the suggested reporting functionality, the fundamental objectives of the project were fulfilled. By utilizing the elements of the eTOD Model toolkit, a beginning GIS user should be able to quickly set up an eTOD analysis and be able to work with their own data in a short time. In the next chapter, the results of running these models will be outlined, with a reflection on the successes and shortfalls of the system implementation.

Chapter 6 – Results and Analysis

This chapter summarizes the outcome of employing the project systems and examines the achievements and the less successful results of the project implementation. Was the desired information produced in a manner requested by the client? Were the designed methods successfully executed in a way that satisfied the requirements of providing an easy to use, low cost eTOD GIS solution? These and other questions will be explored in this penultimate chapter.

By utilizing the eTOD_obstacle geodatabase and running the eTOD Coverage Area models and tools, the user is able to load their data, create the four Coverage Area delineations, and use these derived boundaries to segregate their obstacle data for assessment. For the most part, these functions are carried out with fairly simple steps of selecting the appropriate input data, and with the click of OK automatically create the Coverage Areas and isolate the right obstacle data. But a more thorough look at the implementation of each of the Coverage Areas exposes some of the negative outcomes resulting from the compromises and limitations of the project design.

6.1 Coverage Area 1

The steps and tools used in the Coverage Area 1 model, and their order and sequencing, materialized into the standard from which all the other models were built. The successful running of this model, resulting in the expected outputs, would be a benchmark for the latter models. As with all the models, the tests for Coverage Area 1 used the PLTS tutorial data integrated into the eTOD geodatabase.

Running the Area 1 model with the test data resulted in a very quick generation of the new Area 1 Coverage Area boundary and a simultaneous selection of the obstacles 100 meters or higher within this boundary. For this US data, the Area 1 Feet model was used. The model selected 94 obstacles out of a total of 584, ranging in height from 330 feet to 2000 feet (Figure 6.1). Deleting the new obstacle area created, and rerunning the model repeatedly obtained the same results, as expected. One frustrating requirement in using this model, and those following, was that the user must always refresh the screen to actually see the new obstacle area and the highlighted obstacles. Otherwise, the functions were carried out with a simple one-click solution, a very easy task for the first time GIS user.

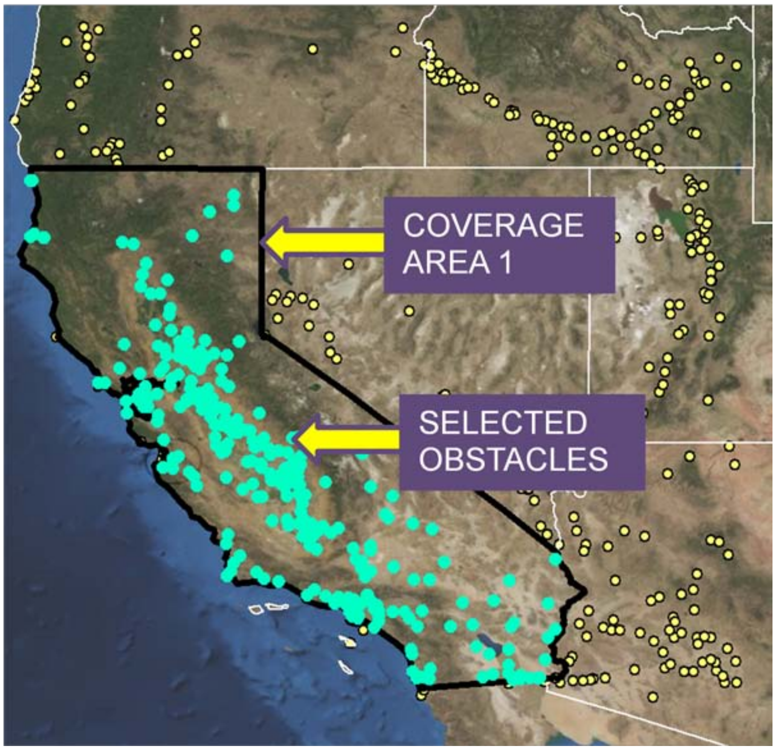


Figure 6.1: Coverage Area 1 Boundary and Obstacle Selection

6.2 Coverage Area 2

For Coverage Area 2, the user must determine which of the toolsets to use: Area 2 – TCA, or Area 2 – 45 km buffer. In most cases the user will be aware if their chosen airport does have a terminal control area (TCA). But if not, the TCA Selection model can be used to create a selection set of TCA airspace. Then the user can zoom to their desired airport and see if there is a TCA above their airport, which will be used for the Area 2 coverage boundary. The eTOD regulations require that the TCA boundary be used only if it has a smaller shape area than the alternative 45 km buffer area. In nearly all cases, the TCA boundary will be smaller, but as a precaution, the user should also run the Area 2 – 45km model. In this way, they can examine the two new obstacle_area features in the attribute table, using the Shape_area field to compare sizes. The area value will seem odd, as it is generated using the decimal degree units of the unprojected data, but they are still useful for comparison purposes. Fortunately, there are few airports that have TCAs, so the user will not have to take the steps for comparison very often. Regardless, using these models is relatively simple and they run almost instantly.

It is important to note that the models for Coverage Area 2 have a noticeable limitation. A method for removing restricted areas from the Area 2 Coverage Areas was not implemented in this project. The first few models developed did successfully remove these areas, but later analysis uncovered that the tools used, like the erase tools, were only available in the higher license levels of ArcGIS. Time constraints hampered the development of alternative methods, which greatly complicated the models. In the end, this functionality was left out. These restricted zones are not widespread, and the ones in the test data for the most part completely covered any associated TCA or 45 km buffer., The Area 2 delineations also are the most abstract for this project, as they do not create the more complex boundaries of the later eTOD revisions, in addition to not being true three-dimensional surfaces. With this in mind, the models progressed without the function of removing the restricted airspace.

6.2.1 Terminal Control Area

The Area 2 – TCA toolset is comprised of two models – TCA Selection, and Create New Obstacle Area. The TCA Selection model runs smoothly and quickly, and helps the user easily create a subset of airspace from which to pick their airport's TCA. Without this step, it is very difficult to select the TCA airspace on the map, as one ends up accidentally selecting many overlapping, airspaces making it frustrating to isolate the desired TCA airspace. Running this model resulted in the quick selection of TCA areas (Figure 6.3), isolating the 60 TCA areas in the test data from a field of 989 airspace possibilities. After refreshing the screen, the user can scan the highlighted TCAs, and chose the one they want to analyze. For the first test, the Modesto Airport TCA was chosen. Next, the user activates the Create New Obstacle Area tool.

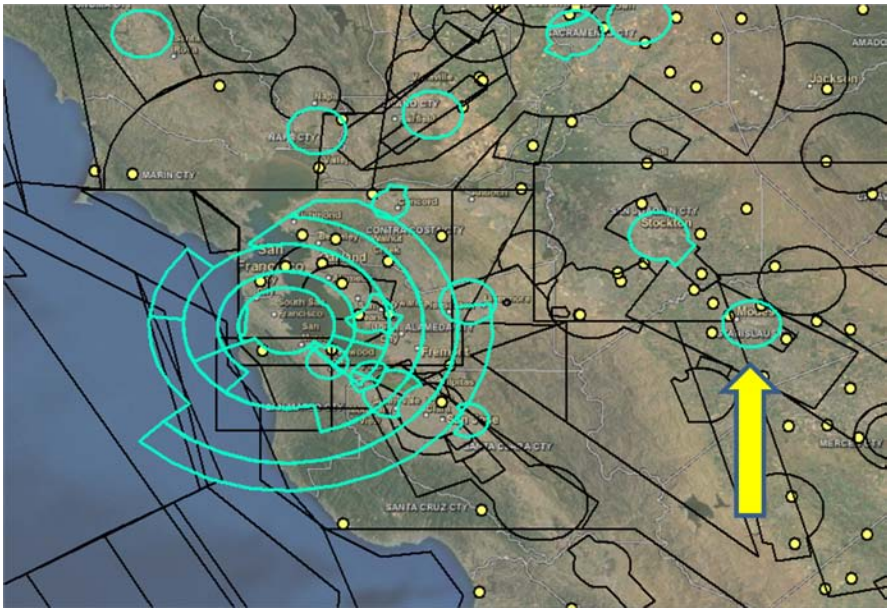
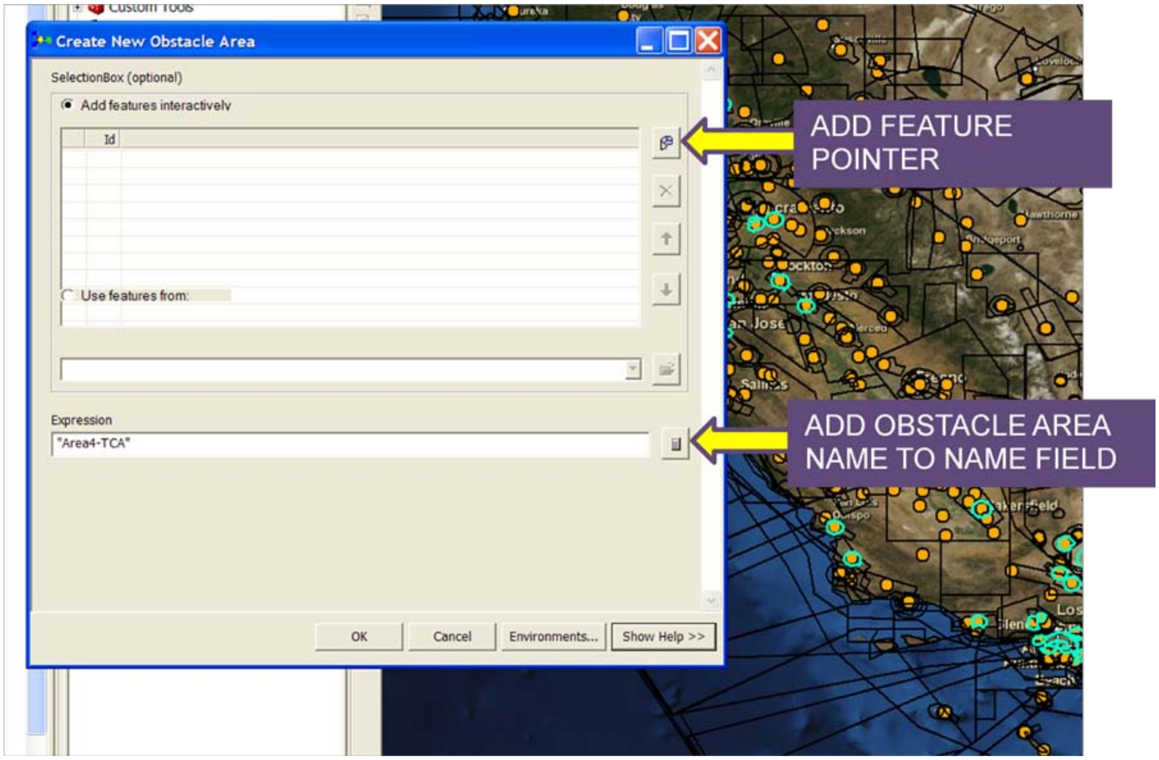


Figure 6.2: Modesto Airport TCA

The next step in completing the Area 1 TCA task is running the Create New Obstacle Areas tool. Here, the selection methodology for using the interactive selection box is introduced. Using the dialogue box can at first be confusing, but after a few tries the user should be able to repeat these steps easily in the same way for each model. Unfortunately, the dialogue box obscures the area where the user has to draw the selection box, requiring an awkward dragging around of the box to get it out of the way, and then dragging it back in view to click the OK button to finish running the model. But, again, with a few tries, this becomes intuitive. The dialogue box also prompts the user for an expression. This is calling for what the user wants to name the obstacle area they are creating. This may be a bit confusing, but the instructions will explain this. It would also have been better if the expression prompt was placed above the selection tool, so that the user would first fill in their name, and then draw the selection box. Still, with some practice, these procedures become easily repeatable.



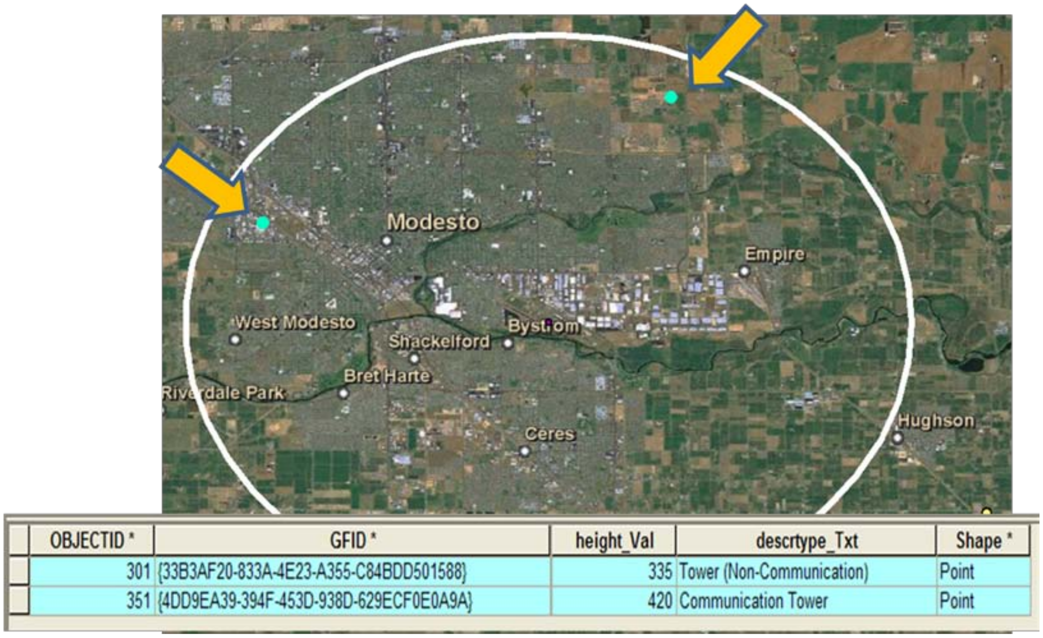
Expression
"Area4-TCA"

ADD FEATURE POINTER

ADD OBSTACLE AREA NAME TO NAME FIELD

Figure 6.3: Selection Tool Dialogue Box

After becoming familiar with the selection process and drawing the selection box, the user clicks OK to run the model, which quickly creates the new obstacle 2 TCA area boundary and selects the obstacles. The Modesto City Airport was chosen in order to test the obstacle selection function, as its TCA has two point obstacles within its boundary, while many in the test data set do not. The model did, in fact, isolate these two tower obstacles (Figure 6.4). From here, the user can select a method to report on the selected obstacles and assess their data quality.



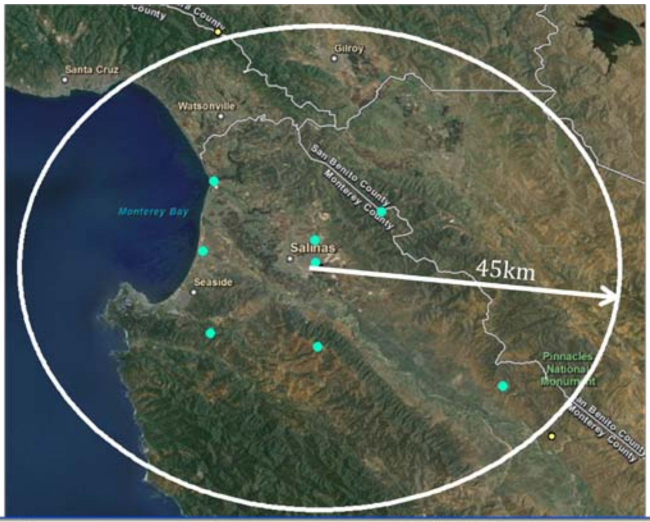
OBJECTID *	GFID *	height_Val	descrtype_Txt	Shape *
301	{33B3AF20-833A-4E23-A355-C84BDD501588}	335	Tower (Non-Communication)	Point
351	{4DD9EA39-394F-453D-938D-629ECF0E0A9A}	420	Communication Tower	Point

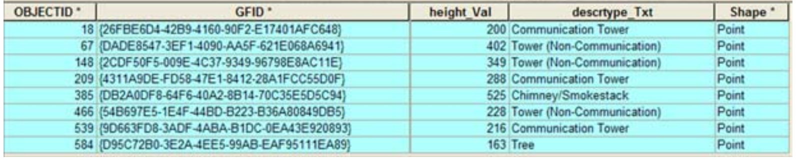
Figure 6.4: TCA Obstacle Selection

The paucity of data for this project hindered the thorough testing of the project somewhat, and to some extent limited its scope. The PLTS tutorial data only provided point obstacle data. This is due to the limitation, until recently, of all obstacles being displayed as points. But recent upgrades to the AIXM model now support line and polygon obstacles, and this project was designed to use them. The models for this prototype solution, however, only select point obstacles at this time. They could easily be modified at a later date to also select line and polygon obstacles. A larger data set, perhaps for an entire nation, would have been very helpful to permit further testing in a larger geographic extent, with a much more dense set of multiple obstacle types.

6.2.2 45 km Buffer

For airports without an accompanying TCA, the Area 2 45 km model is used. Like the Area 1 model, this model is very easy to use, except for the additional step of having to select the proper Aerodrome/Heliport (ADHP), or airport center point. Here, the selection methodology is easy to employ, as the user can draw a very broad box around their intended airport and still make the proper selection for the input data. Once that is accomplished, the user simply runs the tool, which automatically appends a new obstacle_area from the 45 km buffer produced and selects the obstacles within. Since the text case Salinas Municipal Airport does not have a TCA, this is the first time this airport was chosen for analysis. Picking the Salinas ADHP, the model created the new 45 km obstacle_area and chose the associated eight obstacles (Figure 6.5).

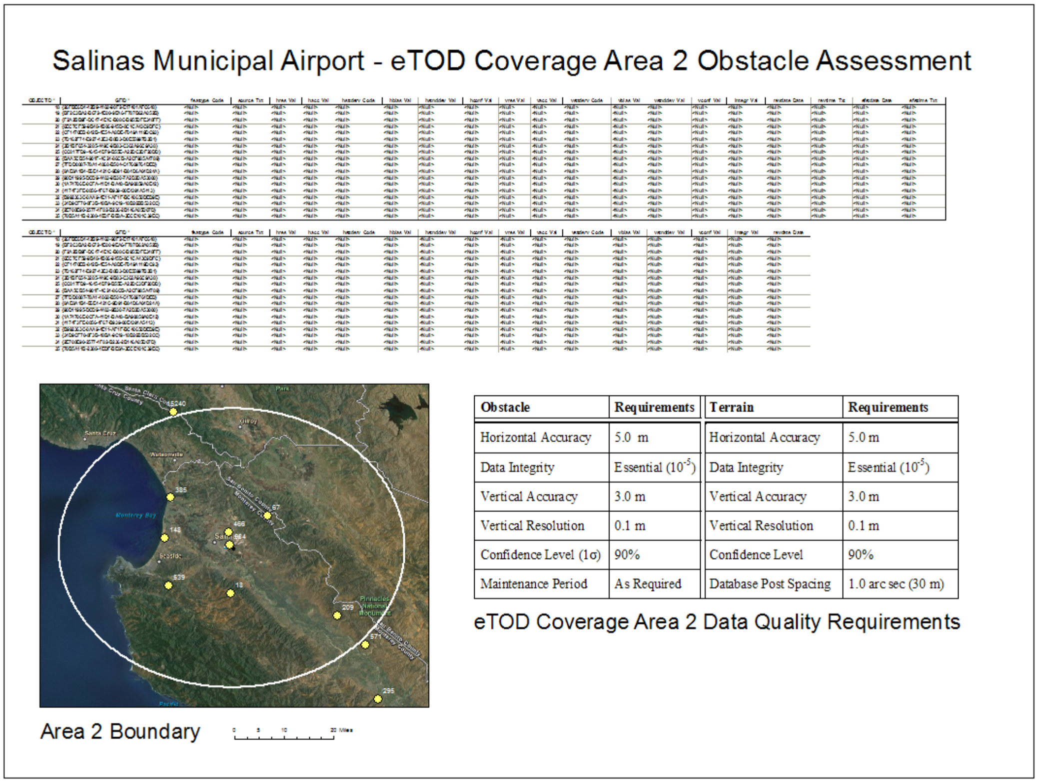




OBJECTID *	GFID *	height_Val	descrtype_Txt	Shape *
18	{26FBE6D4-42B9-4160-90F2-E17401AFC648}	200	Communication Tower	Point
67	{DADE8547-3EF1-4090-AA5F-621E068A6941}	402	Tower (Non-Communication)	Point
148	{2CDF50F5-009E-4C37-9349-96798E8AC11E}	349	Tower (Non-Communication)	Point
209	{4311A9DE-FD58-47E1-8412-28A1FCC55D0F}	288	Communication Tower	Point
385	{DB2A0DF8-64F6-40A2-8B14-70C35E5D5C94}	525	Chimney/Smokestack	Point
466	{54B697E5-1E4F-44BD-B223-B36A80849DB5}	228	Tower (Non-Communication)	Point
539	{9D663FD8-3ADF-4ABA-B1DC-0EA43E920893}	216	Communication Tower	Point
584	{D95C72B0-3E2A-4EE5-99AB-EAF95111EA89}	163	Tree	Point

Figure 6.5: Salinas Airport Coverage Area 2 and Obstacles

This test proved a good example to employ the layout view reporting method – the template provided with the mxd files. The user must follow only a few steps to customize the report for their airport. The titles need to be edited to include their airport name. The user needs to be sure that the data frame is zoomed into the airport to fit well within the Area 2 Boundary map data frame. Probably the most difficult task is getting the attribute table to fit in the suggested format. The table will be inserted in one long row, so the user must make another copy, insert it below the original, and then minimize each view to show all the required fields (Figure 6.6). Once again, with a little practice this becomes a simple task.



Salinas Municipal Airport - eTOD Coverage Area 2 Obstacle Assessment

Obstacle	Requirements	Terrain	Requirements
Horizontal Accuracy	5.0 m	Horizontal Accuracy	5.0 m
Data Integrity	Essential (10^{-5})	Data Integrity	Essential (10^{-5})
Vertical Accuracy	3.0 m	Vertical Accuracy	3.0 m
Vertical Resolution	0.1 m	Vertical Resolution	0.1 m
Confidence Level (1σ)	90%	Confidence Level	90%
Maintenance Period	As Required	Database Post Spacing	1.0 arc sec (30 m)

eTOD Coverage Area 2 Data Quality Requirements

Area 2 Boundary

Figure 6.6: Salinas Coverage Area 2 Report

6.3 Coverage Area 3

The Area 3 model runs efficiently, creating the final dissolved Coverage Area boundary that results from merging the two required buffer areas and successfully selects obstacles within. However, the resultant shape is different from the guideline example, having rounded off edges, rather than the squared off edges of the sample (Figure 6.7) The buffer tools in ArcView only allow the default round end type, so the resulting shape has rounded edges. Technically, this is analytically sound, as the eTOD rules call for buffers around the centerlines and taxiway edges, and a same length buffer around a line end will create a semi-circle. Still, the eTOD rules are ambiguous about this, showing squared off corners in their diagrams. A squared off corner would, in fact, create a larger area within which data could be collected, so the rounded boundaries created by the Area 3 tool might result in missed obstacle selections. However, eTOD committees and those responsible for compiling the eTOD sets are constantly reevaluating these details. For the planning purposes of this project, the rounded Coverage Area 3 is sufficient.

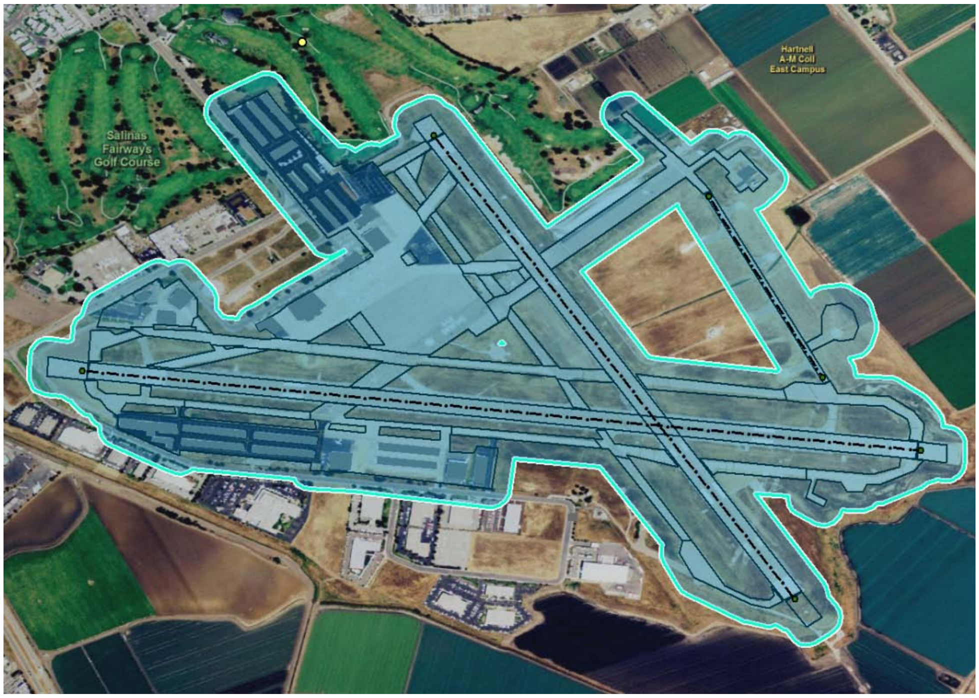


Figure 6.7: Salinas Airport Coverage Area 3

The Area 3 model was run using the Salinas Airport as a test case. For this example, the runway centerline (ADHPSurfaceLine) features for this airport did indeed need to be created, which was simply carried out with an edit session. With the addition of the required runway centerlines, and selection of the required input features with the selection box method, the model ran smoothly. The test case obstacle set does not include any of the high quality, high precision obstacle data one would find in this Coverage Area, but the model does include an obstacle collection step, nevertheless. A few sample point obstacles were placed within the expected boundary to test the obstacle selection function, which worked as expected.

6.4 Coverage Area 4

The method for creating the Coverage Area 4 delineation is the most complex of the four area generation tasks. Fortunately, far fewer airports have runways with the instrument landing Category II & III procedures, and even if they do, usually only one, or a few, runways will have these capabilities and sometimes at only one end. The Coverage Area 4 geometry must be precisely generated, with the long direction of the rectangle being pointed in the exact azimuth direction indicated by the threshold, precisely parallel with the runway, and must start immediately at the threshold point. The Coverage Area 4 toolset contains two models to accomplish this: Preparation and Complete. The Preparation model readies the user to accurately create the parallel extension of the runway and the Complete model uses this line to finish generating the area shape.

As in all the other models, the selection method in the Preparation model ensures that the correct input data is selected. Here, the user draws a simple box around the threshold point as the end of the runway they want to analyze. With this correct point automatically chosen, the model continues on to successfully draw a 900 meter circles around this point. Generating these circles guarantees that any line connecting the threshold to an intersection point tangent to this circle will be exactly 900 meter, the required length of the Coverage Area 4 rectangle. This is exactly what the user does in the intermediary step between using both models.

Creating the new line that will be the centerline of the Area 4 shape is probably the most complicated procedure in the whole project solution. First, the user activates the intersection tool to create a vertex at a point on the 900 meter circle, opposite the threshold and parallel to the runway. With this accomplished, the user merely draws a line between this vertex and the threshold, thus creating the 900 meter line starting exactly at the threshold point, in the same direction as the runway as the eTOD mandates require. Requiring a beginning GIS user to draw a new line may be an advanced task, but they only have to draw one line for the few cases where a runway has a CAT II or III designation. A number of non GIS users were asked to complete this task as an experiment, and with a little prompting, were able to create the line exactly. Once again, the nature of repeating these steps for every airport means that these tasks will get habitually easier to accomplish.

By creating the centerline for the Coverage Area 4 shape, the complicated tasks are over. The user need only select these new lines as input for the next model, the Complete model. With one click, this model creates the 900 meter by 120 meter Coverage Area shape, and selects the obstacles within. As in Coverage Area 3, the buffer tool creates rounded ends on the area shape toolset (Figure 6.8). Because the rounded ends add a half circle area at each end of the boundary, the generated shape creates a larger area that one created with square ends, thus providing a larger obstacle collection area.

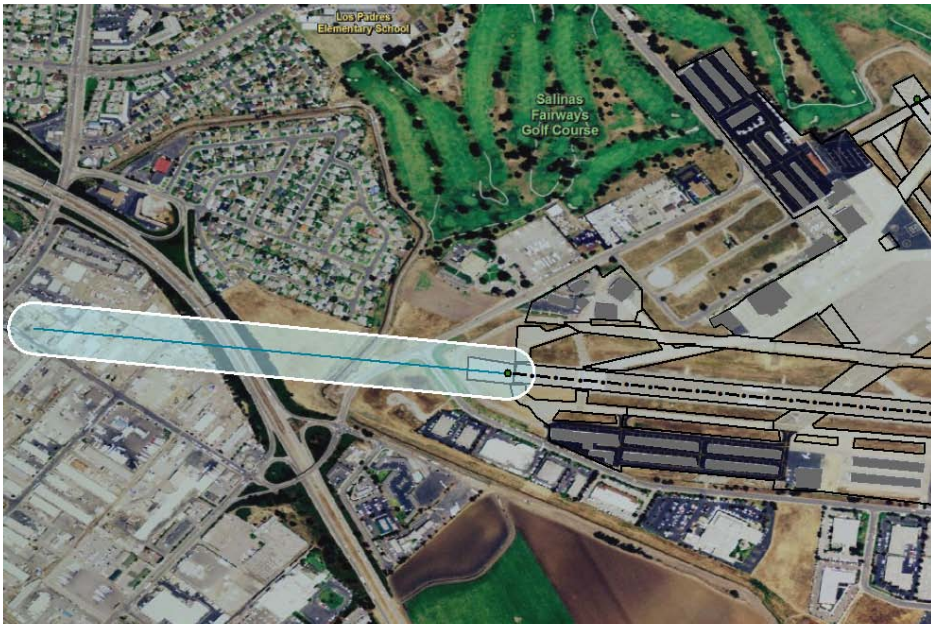


Figure 6.8: Salinas Airport Coverage Area 4

Once again, the test airport Salinas Municipal was used for input data to run the models in Coverage Area 4. The Salinas airport does not actually have instrument landing capabilities, but the Coverage Areas generated illustrates the configuration, shape, and size of a typical Coverage Area 4 outline. And just as in the Area 3 test, the PLTS data set is lacking any high quality obstacle data within the created boundary. Here again, a few sample obstacle points were added, and these points were successfully selected.

Repeated tests of the Coverage Areas tools were successful in creating the required Coverage Areas shapes and selecting the obstacles within. The methods were designed for easy use by beginning GIS users, and the simplicity of using these models for the most part realized that goal. A first time user must practice at first with the selection box method, and the Area 4 editing task may require some extra training. But beyond these more complicated steps, the rest of the functionality works smoothly with the click of a button. Still, there is always room for improvement in any project. And as noted above, some of the functions, like creating the Area 2 shape, have their limitations. In the final chapter, these limitations will be reviewed in the context of the originally stated project objectives, and suggestions for future work to address these shortcomings and expand upon the successes of this project will be discussed.

Chapter 7 – Conclusions and Future Work

After the long duration of completing a project, it is helpful to be reminded of the original intentions and goals in relation to the final implementation and results. With these in mind, it was useful to reflect on the work accomplished. At the outset, what did the project intend to achieve? What were the client's technical and operational requirements? How were these desires eventually implemented, and what were the results of applying the final tools and methodologies? What really worked, and what could have been improved? And finally, what types of supplementary projects could expand upon and extend the usefulness of these efforts? These questions will be explored in this final chapter.

7.1 Project Accomplishments

The primary purpose of this project was to provide a GIS framework to carrying out the organization and planning stages for creating eTOD compliant datasets. The methods and procedures implemented were designed to assist potential clients with limited resources, to begin the process of analyzing their existing terrain and obstacle data, and plan for foreseeable data acquisition.

- First, a file geodatabase was created to accomplish three primary tasks: organize the client's existing aeronautical data; arrange data needed to create the Coverage Area boundaries; and format selected terrain and obstacle data for eventual eTOD submission.
- Second, an eTOD Coverage Area Toolkit was devised that arranges the custom models developed to generate the four required eTOD Coverage Areas.
- Third, procedures were developed to segregate the obstacle data within the derived eTOD Coverage Areas, and report on existing data quality as compared Coverage Area eTOD requirements. These three tasks were successfully implemented in the GIS environment specified by the client, ESRI. This project works with the lowest license level ArcView software, and does not require the use of extensions. Users access the tools and methods through the standard ArcMap and ArcCatalog interfaces.
- Finally, these tools and methods were designed to be used by clients with little to no GIS experience. With a minimum of training, potential users can quickly and easily assess the quality and extent of their existing terrain and obstacle data, and plan for the inevitable acquisition of supplementary data needed to comply with the eTOD mandates.

In order to produce the most functional geodatabase for this project, the database design was augmented throughout the implementation process. First, a trial eTOD_obstacle file geodatabase was created to organize the myriad of aeronautical features and tables. This first step database was used in the beginning stages of project implementation. The geodatabase went through much iteration, functioning in many different roles throughout the project lifecycle.

Through trial and error, a final schema emerged that not only provided a framework for the required project analysis, but also set up a schema for the preliminary formatting of a complete eTOD submittal. The geodatabase primarily integrated aeronautical feature classes from ESRI's PLTS – Aeronautical Solution tutorial data. The latest release of this software incorporated many of the features and accompanying attributes required by the eTOD mandates. A few extra features were added to the database to support the implementation tasks, as well as a few others used to provide backgrounds for the analysis results. Compromises in database design were made along the way because of limitations imposed by using ArcView.. For example, relationship classes, integral to aeronautical data, had to be removed, as ArcView only supports read only access to features with relationship classes. In the end, however, an efficient and well organized database emerged as a best fit for the project goals.

Using the original comprehensive set of PLTS tutorial data, the tools and methods to create the eTOD Coverage Area shapes were developed. By studying the ICAO eTOD guidelines, specifically the rules and diagrams for creating the four Coverage Areas, a conceptual framework for creating these area shapes in ArcMap gradually developed. These conceptual models were evaluated against the tasks used in the PLTS – Aeronautical Solution to build these shapes, even though much of the functionality of PLTS was not available in ArcView. These concepts were then physically realized into a prototypical sequence of tools and procedures using ESRI's Model Builder technology.

At this beginning stage, the project proceeded without noticing that an ArcInfo license was being used. Once this was discovered, the license was switched to ArcView, and the prototype models were run again, noting what tools and functions did not work in ArcView. The resultant revisions actually invigorated the process of enhancing the models.

With a series of iterative tests, the models were improved to make them more efficient and easy to use. They also evolved to utilize a minimum of data, as it is impossible to predict what type of data a potential user will possess. The prototypes coalesced into a final eTOD Coverage Area Toolbox, which contains the individual Coverage Area toolsets. Within these toolsets, the user finds the final models developed to generate the four eTOD Coverage Areas. In addition, each model includes tools to select the obstacles located within the Coverage Areas boundaries. From this selection set, the client can access the attribute values for these obstacles in the attribute table and compare them to the eTOD data quality standards. They can copy the table to Excel for custom formatting, print out an Adobe PDF report which automatically formats the table layout, or use the layout view templates in ArcMap which incorporate a map of the Coverage Area and a list of the suitable eTOD rules.

The successful development of an effective eTOD-obstacle geodatabase and the final Coverage Area models did fulfill the functional requirements set out by the client, ESRI. Using the methods defined in this project, the client is able to organize their aeronautical data and begin the process of formatting it to eTOD standards. By utilizing the Coverage Area models, they are able to quickly and easily segregate their existing obstacle data into the appropriate Coverage Areas in order to assess the quality of their existing data in comparison to eTOD standards. For the most part, the models are easy to use, requiring a minimum of input from a beginning GIS user. The models still require users to select the input data for the models, which can be confusing for a beginning user, and the Coverage

Area 4 model necessitates the user to draw new lines, which is a somewhat complicated edit session in ArcMap. But apart from these challenges, the models are mostly a one click solution. Still, any project can always be improved, and a look at some specific suggestions to improve upon this prototype eTOD solution proposes possibilities for useful extensions to this work

7.2 Future Work

Improvements to the functionality and usefulness of this eTOD solution provide interesting challenges for future work. First, a more complete eTOD solution could be developed utilizing custom programming and scripting, providing improved dialogue boxes and true, one click functions. Second, an enterprise system design could be implemented to greatly enhance the program function efficiencies and provide for simultaneous use of solution data and tools. An third, a system design using three-dimensional analysis is essential to precisely select the appropriate terrain and obstacles for Coverage Area 2, and work interactively between terrain and obstacle data. Each of these expansions to the eTOD model functionality would make excellent future projects.

With the goal of providing easy methods for first time GIS users, the Coverage Area models could be improved, going beyond the limitations of using core ArcGIS tools in Model Builder. By utilizing custom scripting and programming to enhance the project implementation, eTOD specific tools could be created with specialized interfaces that guide the user step-by-step through the process; much like Task Assistant Manager does in PLTS. Such procedures would greatly improve the data input selection process, significantly simplify creating the Coverage Area 4 boundaries, and provide more simple, one-click methods for beginning users to employ.

This project was designed for clients to use with one solitary computer on which they host their own aeronautical data. Creating eTOD sets for all a nation’s airports is ultimately impractical if the user is employing these tools on only one computer. The models could be improved to create all the Coverage Areas for all the airports simultaneously. This would require that procedures be developed to organize this massive amount of data. But the time advantage of creating all the required sets at once, especially in light of the looming eTOD deadlines, would be significant. Batching could be successfully utilized to run the models without supervision. Beyond these improvements, developing an enterprise system for eTOD obstacle analysis would be very advantageous. Vast national aeronautical datasets could be centrally administered, and multiple users could complete the analysis for many airports simultaneously. Anything to improve the speed and efficiency of creating the eTOD sets would be eagerly met by the parties responsible for their ultimate submission.

A final improvement to an eTOD solution would be integrating three-dimensional capabilities into the model. This project creates only the two-dimensional boundaries of the Coverage Areas to be used for initial data assessment and planning, but a final eTOD solution must be able to select obstacles by their heights in relation to terrain. For Coverage Area 2, the shape is actually a complex collection of sloping planes and surfaces. Obstacles that penetrate this surface must be selected to comply with the eTOD standards. This requires three-dimensional analyses, which were prohibited in this project. A fully functional final eTOD solution must have the capabilities to perform these complicated obstacle selection tasks in order to create a precise and complete eTOD set.

The International Civil Aviation Organization has launched a challenging goal to overhaul the world's air traffic control system. A fundamental step toward this transformation is implementing a new paradigm of air traffic management that harnesses the benefits of modern computer-based GPS surveillance and communications. The eTOD mandates are a vital first step towards creating this revitalized system, requiring the establishment of digital aeronautical data that will underpin these new systems. The eTOD mandates are challenging and the deadlines for compliance are fast approaching. This project proposes a first step GIS solution for initializing the eTOD compliance process. The tasks and procedures introduced here are part of a global effort to provide an air traffic management system that is safer, handles much higher traffic capacity, and is more environmentally sensitive. With our current system reaching critical capacity, this long awaited overhaul cannot come soon enough.

Works Cited

Brochard, M. (2007). The Air Traffic Management System for 2050 - Virtual - Global - Automated. *First CEAS European Air and Space Conference* (pp. 559-563). Berlin: The Council of the European Aerospace Societies.

Brunk, B. (2007). AIXM 5 Concepts. *AIXM Class 2007* (p. 40). Washington D.C.: FAA/Eurocontrol.

Brunk, B. (2008). Introduction to AIXM. *Civil Aviation Authority of Singapore - Singapore Workshop - Technical Focus*, (pp. 1-21). Singapore.

Brunk, B. K., & Porosnicu, E. (2005). Aeronautical Information Exchange Model (AIXM) GIS Interoperability through GML. *Proceedings of the Twenty-Fifth Annual ESRI User Conference.* San Diego, CA: ESRI.

Department of Defense and Department of Transportation. (2001). *2001 Federal Radionavigation Systems.* Washington, DC: Department of Defense and Department of Transportation.

Eckland, K. O. (2007, April 04). *AvSpeak - A Glossary of Aviation Terms and Abbreviations*. Retrieved July 29, 2009, from Aerofiles - A Century of American Aviation: http://www.aerofiles.com/glossary.html

ESRI. (2003, March 2). *GIS Solutions ofr Airports and Aviation.* Retrieved October 12, 2008, from ESRI: http://www.esri.com/library/brochures/pdfs/airports-aviation.pdf

ESRI. (2008). *PLTS for ArcGIS - Aeronautical Solution*. Retrieved October 4, 2008, from ESRI: http://www.esri.com/software/arcgis/extensions/plts/solutions/aeronautical.html

ESRI. (2009). *ESRI GIS Provides Improved Support for eTOD Implementation,* from ESRI Press Release, March 11, 2009

Federal Aviation Administration. (2008). *Implementing Tomorrow's Solutions Today - NextGEN.* Federal Aviation Administration.

Freer, D. W. (1987). ICAO at 50 Years: Riding the Flywheel of Technology. *ICAO Journal , 49* (7), 19-32.

Graham, D.,Vidal, S., & Steele, J. (2005). FAA Airport Surveying--GIS Program. *Twenty-Fifth Annual ESRI User Conference.* San Diego,CA: ESRI.

Intergovernmental Panel on Climate Change. (1999). *Aviation and the Global Atmosphere.* Retrieved May 31, 2009, from Intergovernmental Panel on Climate Change: http://www.ipcc.ch/pdf/special-reports/spm/av-en.pdf

International Air Transport Association. (2003). *One Sky…global ATM – the way forward.* Montreal: International Air Transport Association.

International Civil Aviation Organization. (2008, October 10). *ACI Global Traffic Forecast Report 2008 - 2027.* Retrieved May 31, 2009, from International Civil Aviation Organization: http://www.icao.int/ceans/Docs/Ceans_Wp_066_en.pdf

International Civil Aviation Organization. (2005a). *Annex 15 to the Convention on Civil Aviation.* Montreal: International Civil Aviation Organization.

International Civil Aviation Organization. (2005b, January 26). *Strategy Guiding International Civil Aviation in the 21st Century.* Retrieved October 29, 2008, from International Civil Aviation Organization: http://www.icao.int/icao/en/sap1997_en.pdf

International Civil Aviation Organization. (2007a). *Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information.* Montreal: International Civil Aviation Organization.

International Civil Aviation Organization. (2007b, February 12). *The Convention on International Civil Aviation Annexes 1 to 18.* Retrieved June 5, 2009, from International Civil Aviation Organization: http://www.icao.int/icaonet/anx/info/annexes_booklet_en.pdf

International Civil Aviation Organization. (2009, May 11). *Implementation of Electronic Terrain and Obstacle Data.* Retrieved June 4, 2009, from www.icao.int/wacaf/apirg/sg/2009/AIS_MAP_TF5/docs/WP4%20AIS%20MAPTF-5.doc

International Civil Aviation Organization. (1997). *Strategic Objectives.* Retrieved June 3, 2009, from ICAO: http://www.icao.int/icao/en/sap1997_en_app.pdf

Joint Economic Committee. (2008, May 22). *Your Flight Been Delayed Again.* Retrieved May 31http://jec.senate.gov/index.cfm?FuseAction=Reports.Reports&ContentRecord_id=11116dd7-973c-61e2-4874-a6a18790a81b&Region_id=&Issue_id, 2009, from U.S. Congress Joint Economic Committee.

Neubert Aero Corporation (NAC). (2007). *Aviation GIS*. Retrieved June 11, 2009, from NAC Airport Product and Services: http://www.airportnac.com/AviationGIS.aspx

Pal, T. (2008). *Electronic Terrain and Obstacle Database (eTOD).* Redlands, CA: ESRI.

Pavlovic, A. (2008). Electronic Terrain & Data Obstacle Quality Requirement. *ETOD Forum 2008.* Saanenmoser, Switzerland.

Pavlovic, A. (2007, May 14). *Electronic Terrain and Obstacle Data.* Retrieved September 19, 2008, from Lima - ICAO: www.lima.icao.int

Reid, K. (2008). Electronic Terrain an Obstacle Data. *Global Aim Workshop.* Singapore: Eurocontrol.

SPG Media. (2006, September 1). *On the Ground or in the Air: GIS for Aviation - ESRI.* Retrieved June 4, 2009, from Airport-Technology: http://www.airport-technology.com/features/feature760/

U.S. Department of Transportation - Federal Aviation Administration. (2008). *Aeronautical Information Manual - Official Guide to Basic Flight Information and ATC Procedures.* Washington, D.C.: Federal Aviation Administration.

United States Air Force. (2009). *Determine AHAS Risk*. Retrieved June 11, 2009, from United States Avian Hazard Advisory System: http://www.usahas.com/