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METHODS OF IMPLEMENTING INFORMATION SYSTEMS FOR GEOSPATIAL DATA IN THE AVIATION INDUSTRY

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1. Introduction

As the urbanization tendency grows worldwide, the aviation industry has driven the need for an increase in complexity in its information system. According to an United Nations study about World Urbanization prospects, in 2014, the urban population across the globe has reached 54% and continues to increase. This requires spatial planning, which plays a strategic role in the development process.

Because most aerodromes worldwide, are situated in the vecinity or even embedded in cities, efficient management of urban areas demands quick and precise methods for visualizing and analyzing geospatial information.

In order to improve the interpretation and use of aeronautical information, global standardization is needed.

Moreover, the use of a common aeronautical language as well as the application of sets of rules and procedures for the production and distribution of aeronautical information allows interoperability.

Thus, standardization, as an iterative process, is closely related to interoperability.

The methods and tools used for managing, processing, analyzing and transferring spatial data are the basis for implementing complex information systems. The design phase, the various methods of data collection, the need for coordinate transformations, the errors that are propagating through the processing phase and data quality must be taken into account.

The methods and techniques for geospatial data acquisition were presented in the Scientific Research Report no.1.

This report is structured in four chapters and expands on various methods and phases for implementing an aeronautical information system.

The first chapter presents an overview regarding aeronautical studies, the need for an aeronautical information system, as well as the abstract.

The second chapter describes the steps taken to process spatial data, so that it can be integrated into the database, validated, manipulated in analysis processes and distributed in the specific format, according to the aeronautical regulations.

The third chapter analyses current technologies, platforms and applications that provide an efficient way to perform aeronautical studies, through special tools created for operational process automation, based on predefined workflows, in order to obtain publishable products.

The final chapter is reserved for conclusions.

2. Spatial data for GIS systems in the aviation industry

2.1. GNSS data

2.1.1. General considerations

In order to obtain the spatial coordinates from GNSS data processing, the following steps need to be taken:

- processing GNSS observations by combining the recordings from L1 and L2 frequencies, the code measurements with phase measurements, leading to obtaining the coordinates for the new stations in the global reference system, WGS-84;
- transforming these coordinates into each country's own datum; in the case of Romania, the coordinate reference system is S42, which is based on Krasovski 1940 ellipsoid, defined by the coordinate system in Stereographic 1970 projection on a unique secant plane, and respectively Black Sea 1975 altitude system.

GNSS observations are processed depending on the measurement method, the coordinate system used and the type of measurements performed in the network.

To aid with transforming the coordinates from one datum to another, the National Agency for Cadastre and Land Registration of Romania has implemented a national application called TRANSDAT.

Most of the processing software for GNSS observations will perform the calculations using the following steps [1]:

- calculating provisional coordinates for the station, based on those of the satellites deducted from ephemeris and the pseudodistance, phase or code measurements, Doppler effect or the triple differences of the phase measurements on the carrier;
- data checks for identifying and potentially removing false measurements or interruptions in the phase measurements;
- estimating parameters and results analysis.

2.1.2. Particularities for the aviation industry

According to ICAO standards, the coordinates of the points in the topographic network must be referenced to the global reference system, WGS-84.

In order to comply with this format, these coordinates need to be converted from ETRS89 coordinate system into WGS-84 coordinate system, using the Helmert transformation parameters. Both coordinate systems are well defined, hence the transformation will not affect the quality and accuracy of the coordinates.

The 7-parameter Helmert algorithm is used to transform the coordinates from the global reference system WGS-84 into S42 coordinate system, which is based on Krasovski 1940 ellipsoid and the coordinate system in Stereographic 1970 projection plane, with altitudes in Black Sea 1975 coordinate system.

The coordinate transformations have been studied in the Scientific Research Report no.1.

2.2. LiDAR data processing

2.2.1. General considerations

LiDAR data processing is done based on the following two steps: data *pre-processing*, which is performed during the flight, allowing for a certain level of data quality control, followed by *post-processing*.

The registration results, the coordinate transformation of the data collected from multiple scans in the same coordinate system, can be influenced by the quality of the point clouds, driving the need for data pre-processing. [2]

Georeferencing or point cloud aggregation in a unique system, is performed in the post-processing phase, however this step can be avoided if data registration is according to a defined coordinate system. [2]

- *Direct georeferencing* is the transformation of a point's coordinates from the scanner's system into an external system. This method doesn't require overlapping scans and it's faster than indirect georeferencing. [3]

- *Indirect georeferencing* requires known coordinate points or tie points located in the scan area. For each scan, a minimum of three of these known points need to be visible.

Dataset alignment between multiple point clouds requires identifying a minimum of three points, common to all datasets. Using the *Iterative Closest Point* (ICP) algorithm, the distances between all points within the point clouds are verified sequencially, in order to perform the coordinate transformation with minimal errors. [2]

Following the registration and georeferencing operations, the resulting common point cloud can be used in the modeling process.

Noise filtering and gross errors removal is recommended, in order to reduce the time required for point cloud processing. [2]

In order to obtain digital models, the point cloud is classified as either terrain, vegetation or building point classes.

The Digital Surface Model (DSM) is then filtered, taking into account breaklines and applying geometrical tests and an interpolation method, in order to obtain the altimetric digital model. [4]

There are multiple interpolation methods for surface modeling, based on the 2D or 3D orientation. Two significant methods are the Delaunay triangulation method, using linear interpolation for irregular networks, or the cubic spline interpolation (natural neighbour), generating the Voronoi diagram.

Following the correction and validation of the point classes, the 3D modeling activity can start. The result of modeling is a mesh of triangles and quadrilaterals, connecting all points from the cloud, taking into account topological links between triangles and adjacent items. This resulting mesh can also be reffered to as a TIN surface model.

2.2.2. Particularities for the aviation industry

LiDAR data aquisition and processing is handled differently for the aeronautical studies.

Data accuracy is highly dependant on the flight mission operational parameters, system calibration, GNSS data quality, as well as the type of terrain studied.

For aeronautical studies, it is essential to use all generated point clouds, with every returned signal (first, last and intermediate), without filtering and eliminating points. Abnormal readings are stored in the file, but classed as withheld, as required by LAS file format. [5]

It is absolutely necessary that the processing starts with data from the point clouds; interpolated digital surface models are not permitted as inputs for processing, due to the fact that 2D elevation grids do not represent the vertical structure adequately. [5]

A typical workflow for LiDAR data processing, adapted for the high accuracy needs and requirements for the aeronautical studies, is described below:

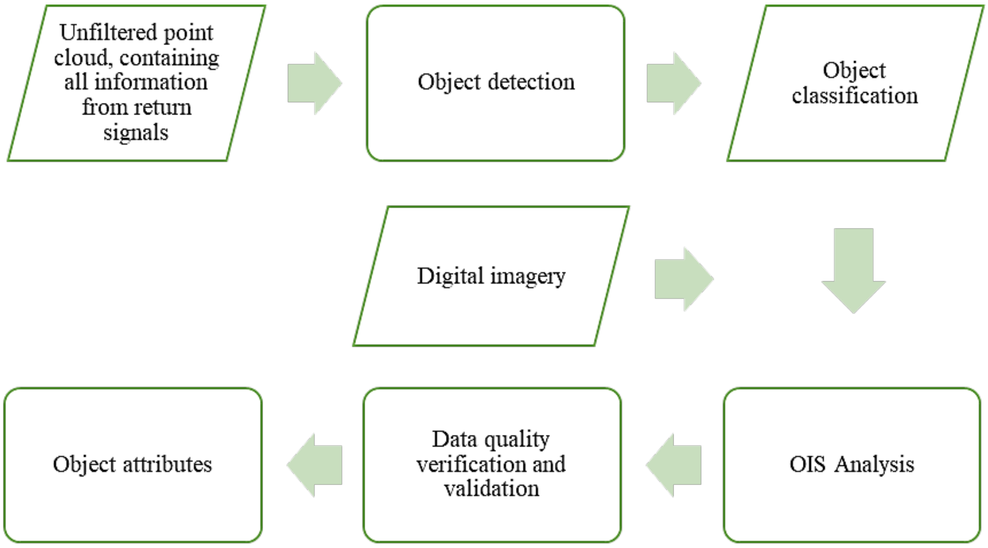


Figure 2.1. LiDAR data processing workflow

A critical aspect in this workflow (Figure 2.1) is placing the object detection stage prior to Obstacle Identification Surfaces (OIS) analysis, in order to perform this analysis on extracted objects (trees, buildings, antennae, poles, towers, etc.) rather than on raw LiDAR points [5]

Regardless of the algorithm used for object detection, the key element in this process is setting the threshold for detection at a suitable level, to diminish the possibility of object omission. [5]

False alerts caused by noise will be eliminated in the OIS analysis phase, either because they do not penetrate the OIS, or are placed outside of these surfaces. [5]

Using LiDAR data and digital imagery offers complementary information, required for processing. A variation of this workflow includes the contribution of aerial imagery to facilitate photogrammetric obstacle detection, with LiDAR assist. [5]

2.3. Photogrammetric data processing

2.3.1. General considerations

In order to generate digital terrain models, Digital Surface Model (DSM), Digital Terrain Model (DTM) and orthophotos, the process follows the steps below:

- Removal of unsuitable images (blurry, tilted, underexposed, overexposed);
- Radiometric correction of images;
- Image alignment (interior orientation and relative orientation);
- Generation of tie point cloud between images;
- Image point marking and establishing control points and check points;
- Optimizing image alignment (georeferencing the stereomodel - exterior orientation and transformation parameters analysis);
- Block aerotriangulation;
- Generation of correlated point cloud / dense point cloud *;
- Generation of the Digital Surface Model (DSM);
- Orthomosaic generation;
- Editing mosaic lines; geometry editing; texture generation;
- Export of orthophotos;
- * Classification of the correlated point cloud;
- Generation of the Digital Terrain Model (DTM) based on terrain points class;
- Generation of the verification report.

The effectiveness of photogrammetric studies is given by the automation process and correct correlation between images.

2.3.2. Particularities for the aviation industry

From the early stages of the spatial data acquisition process, the study particularities need to be carefully considered, in order to optimize data processing, by highlighting the following key elements:

- using a large number of ground control points, positioned with high accuracy (using total stations and station points' coordinates acquired with GNSS technology). These control points are the key element in geometric reconstruction, as they represent the link between the image model and the terrain model, essential in georeferencing.

- Image alignment:

- *Accuracy*: using the *High* option, allows for a precise estimation for the position of perspective centers. Processing is performed on the original size of the image.

– *Pair preselection*: the *Reference* option permits image pair selection based on the perspective centre coordinates.

- Generating the dense point cloud – selecting a higher value for quality aids with obtaining a precise and detailed geometry. The *Ultra High* option allows the data processing to use the original size of the image, while the *High* option reduces the size of the image used for processing by a factor of 4.

3. GIS systems for the aviation industry

A GIS system is required to efficiently manage spatial data.

The geospatial database contains elements that are described in different formats:

- Vector data types – point, line, polygon;

- Raster data;

- Irregular triangulation networks - for surfaces.

Data elements are models of spatial objects, grouped into thematic classes, within the dataset.

Geospatial data can only be made available by implementing conceptual and methodological databases, taking into account the descriptive standards for these datasets and the formats for data exchange. [6]

The modeling process influences the spatial analysis process, so any decision that is made regarding the data model is essential for the success of the project. [7]

3.1. Types of database entities

3.1.1. Obstacle limitation surfaces

Obstacle Limitation Surfaces (OLS) are the surfaces designed around an aerodrome, used to set the objects' height limits. Objects that are penetrating these surfaces become obstacles.

Obstacle limitation surfaces are described as follows, according to RACR-AD-PETA [9] and ICAO Annex 14 to the Chicago Convention [10], Volume I, Chapter 4 (Figure 3.1):

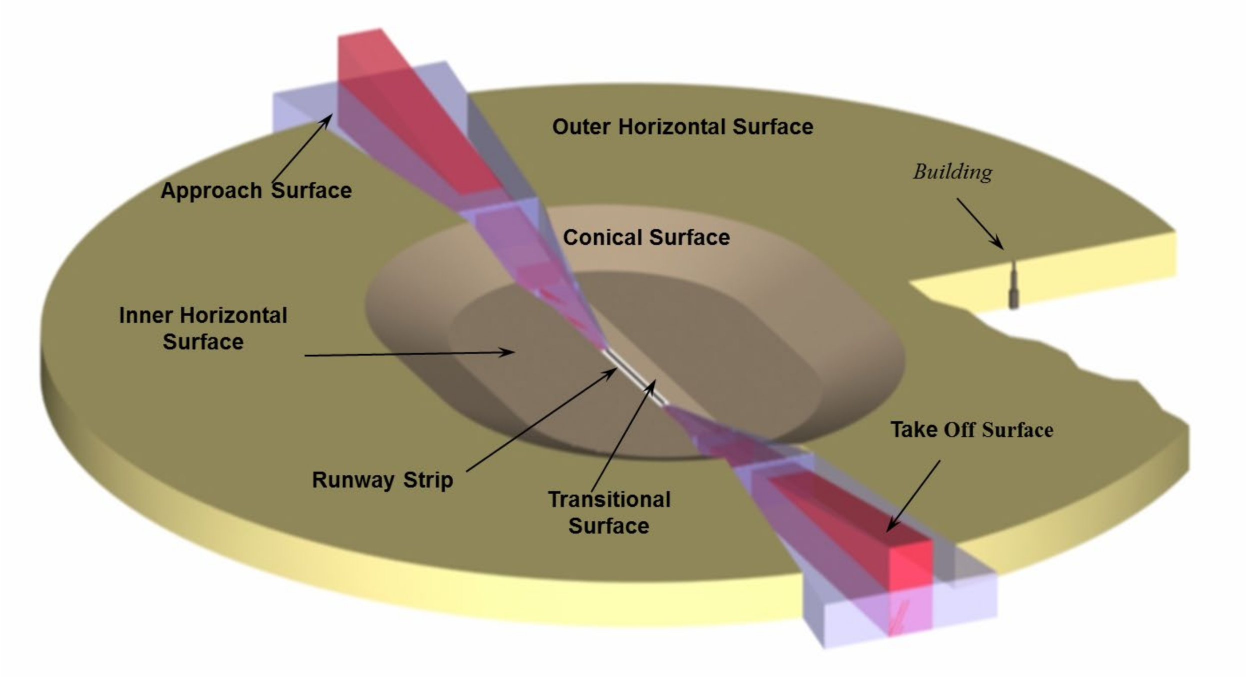


Figure 3.1. Obstacle limitation surfaces

*„**Inner horizontal surface** – A surface located in a horizontal plane above and around an aerodrome, at a specified height relative to an altitude reference element, with the radius or outer limits measured from one or more reference points . " [9], [10]*

*„**Conical surface** – A surface sloping upwards and outwards from the edge of the inner horizontal surface, at a specified height above the inner horizontal surface, with a slope measured in a vertical plane perpendicular to the edge of the inner horizontal surface. ”[9], [10]*

*„**Approach surface** – An inclined plane, or a combination of planes extending at a specified distance from the runway threshold, with the inner edge of specified length, horizontal and perpendicular to the extended runway centerline, two sides originating at the ends of the inner edge, with a divergence from the extended runway centerline, with the outer edge parallel to the inner edge, and the slope measured in a vertical plane perpendicular to the runway centerline. ”[9], [10]*

*"**Inner approach surface** - A rectangular portion of the approach surface, which extends at a specified distance from the runway threshold, having the inner edge coincident with the inner edge of the approach surface and the specified length, two sides originating at the ends of the inner edge and extending parallel to a vertical plane containing the runway centerline, the outer edge parallel to the inner edge, and the specified slope. ”[9], [10]*

*„**Transitional surface** - A complex surface along the side of the runway strip and part of the side of the approach surface, with an ascending slope and outwards to the intersection with the inner horizontal surface. The lower edge is defined from the intersection between the edge of the approach surface and the inner horizontal surface, descends along the edge of the approach surface to the inner edge of the approach surface and continues along the length of the strip parallel to the runway centerline. The upper edge is located in the plane of the inner horizontal surface. ”[9], [10]*

*„**Balked landing surface** – An inclined plane with a specified slope, located at a specified distance after the runway threshold, extending between the inner transitional surface, with the inner edge horizontal, perpendicular to the runway centerline, two sides originating from the ends of the inner edge, divergent from a vertical plane containing the runway centerline, and the outer edge parallel to the inner edge and located in the plane of the inner horizontal surface. ”[9], [10]*

*„**Inner transitional surface** – A surface similar to the transitional surface, bounded by the inner edge of the inner approach surface, extending along the strip parallel to the runway centerline to the inner edge of the balked landing surface at the point where it intersects the inner horizontal surface;the upper edge located in the plane of the inner horizantal surface. The slope of the inner transition surface must be measured in a vertical plane perpendicular to the runway centerline. [55], [56]*

*„**Take-off climb surface** – An inclined plane extending at a specified distance from the end of a runway or clearway, with the inner edge horizontal and perpendicular to the runway centerline, two sides originating at the ends of the inner edge, with a divergence with respect to the take-off direction to a specified final width, continuing at this width for the remainder of take-off climb surface, and an outer edge horizontal and perpendicular to the specified take-off direction. " [9], [10]*

*„**Outer horizontal surface** - The surface contained in a horizontal plane, at a height of 150 m above the aerodrome altitude point, extending from the edge of the conical surface, having a radius of up to 15000 m from the aerodrome reference point (ARP), where the runway code is 3 or 4. ”[11]*

The specifications of the obstacle limitation surfaces are described as follows, according to RACR-AD-PETA [9] and ICAO Annex 14 to the Chicago Convention [10], Volume 1, Chapter 4 (Table 3.1, Table 3.2):

Table 3.1. Dimensions and slopes of obstacle limitation surfaces; Approach Runways [10]

Surfaces and dimensions	RUNWAY CLASSIFICATION									
	Non-instrument approach				Non-precision approach			Precision approach category		
	Code number				Code number			I		II and III
	1	2	3	4	1, 2	3	4	1, 2	3, 4	3, 4
CONICAL SURFACE										
Slope	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Height	35 m	55 m	75 m	100 m	60 m	75 m	100 m	60 m	100 m	100 m
INNER HORIZONTAL SURFACE										
Height	45 m	45 m	45 m	45 m	45 m	45 m	45 m	45 m	45 m	45 m
Radius	2000 m	2500 m	4000 m	4000 m	3500 m	4000 m	4000 m	3500 m	4000 m	4000 m
INNER APPROACH SURFACE										
Width	-	-	-	-	-	-	-	90 m	120 m	120 m
Distance from threshold	-	-	-	-	-	-	-	60 m	60 m	60 m
Length	-	-	-	-	-	-	-	900 m	900 m	900 m
Slope	-	-	-	-	-	-	-	2.5%	2%	2%
APPROACH SURFACE										
Length of inner edge	60 m	80 m	150 m	150 m	150 m	300 m	300 m	150 m	300 m	300 m
Distance from threshold	30 m	60 m	60 m	60 m	60 m	60 m	60 m	60 m	60 m	60 m
Divergence (on each side)	10%	10%	10%	10%	15%	15%	15%	15%	15%	15%
The first section										
Length	1600 m	2500 m	3000 m	3000 m	2500 m	3000 m	3000 m	3000 m	3000 m	3000 m
Slope	5%	4%	3.33%	2.5%	3.33%	2%	2%	2.5%	2%	2%
Second section										
Length	-	-	-	-	-	3600 m	3600 m	12000 m	3600 m	3600 m
Slope	-	-	-	-	-	2.5%	2.5%	3%	2.5%	2.5%
Horizontal section										
Length	-	-	-	-	-	8400 m	8400 m	-	8400 m	8400 m
Total length	-	-	-	-	-	15000 m	15000 m	15000 m	15000 m	15000 m
TRANSITIONAL SURFACE										
Slope	20%	20%	14.3%	14.3%	20%	14.3%	14.3%	14.3%	14.3%	14.3%
INNER TRANSITIONAL SURFACE										
Slope	-	-	-	-	-	-	-	40%	33.3%	33.3%
BALKED LANDING SURFACE										
Length of inner edge	-	-	-	-	-	-	-	90 m	120 m	120 m
Distance from threshold	-	-	-	-	-	-	-		1800 m	1800 m
Divergence (on each side)	-	-	-	-	-	-	-	10%	10%	10%
Slope	-	-	-	-	-	-	-	4%	3.33%	3.33%

Table 3.2. Dimensions and slopes of obstacle limitation surfaces; Take-Off Runways [9], [10]

Surface and dimensions	Code number		
TAKE OFF CLIMB SURFACE	1	2	3 or 4
Length of inner edge	60 m	80 m	180 m
Distance from runway end	30 m	60 m	60 m
Divergence (on each side)	10%	10%	12.5%
Final width	380 m	580 m	1200 m
			1800 m
Length	1600 m	2500 m	15000 m
Slope	5%	4%	2%

3.1.2. Terrain and Obstacle data collection surfaces

Coverage areas for electronic terrain and obstacle data sets shall be specified as follows, in accordance with RACR-AIS [12] and ICAO Annex 15 to the Chicago Convention [13], Chapter 10:

*„**Area 1**: covers the entire territory of a state;*

***Area 2**: within the vicinity of the aerodrome, subdivided as follows (Figure 3.2):*

- ***Area 2a**: a rectangular area around the runway that comprises the runway strip and clearway (if any).*
- ***Area 2b**: an area extending from the ends of Area 2a, in the direction of departure, with a length of 10 km, a divergence of 15% on each side and a slope of 1.2%.*
- ***Area 2c**: an area extending outside Area 2a and Area 2b at a distance of not more than 10 km from the boundaries of Area 2a, with a slope of 1.2%.*
- ***Area 2d**: an area outside Areas 2a, 2b and 2c up to a distance of 45 km from the aerodrome reference point (ARP) or an existing terminal control area (TMA) boundary, whichever is nearest.*

***Area 3**: an area bordering an aerodrome movement area that extends horizontally from the edge of the runway to 90 meters from the runway centerline and 50 meters from the edge of all other parts of the movement area (Figure 3.3).*

***Area 4**: a rectangular area extending 900 meters prior to the runway threshold and 60 meters each side of the extended runway centerline in the direction of the approach on a precision aproach runway, Category II or III (Figure 3.3).*

When terrain at a distance greater than 900 m (3000 ft) from the runway threshold is mountainous or otherwise significant, the length of Area 4 should be extended to a distance not exceeding 2000 m (6500 ft) from the runway threshold. " [12], [13]

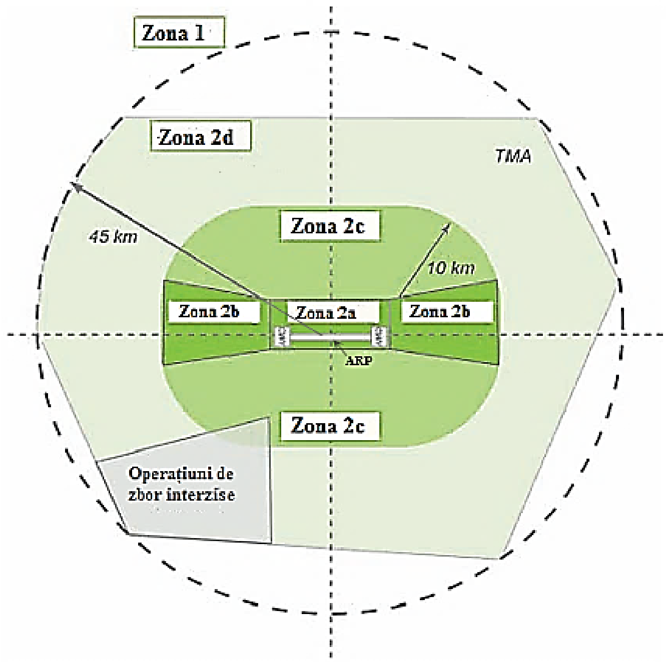


Figure 3.2. Terrain and obstacle data collection surfaces, Area 1 and Area 2

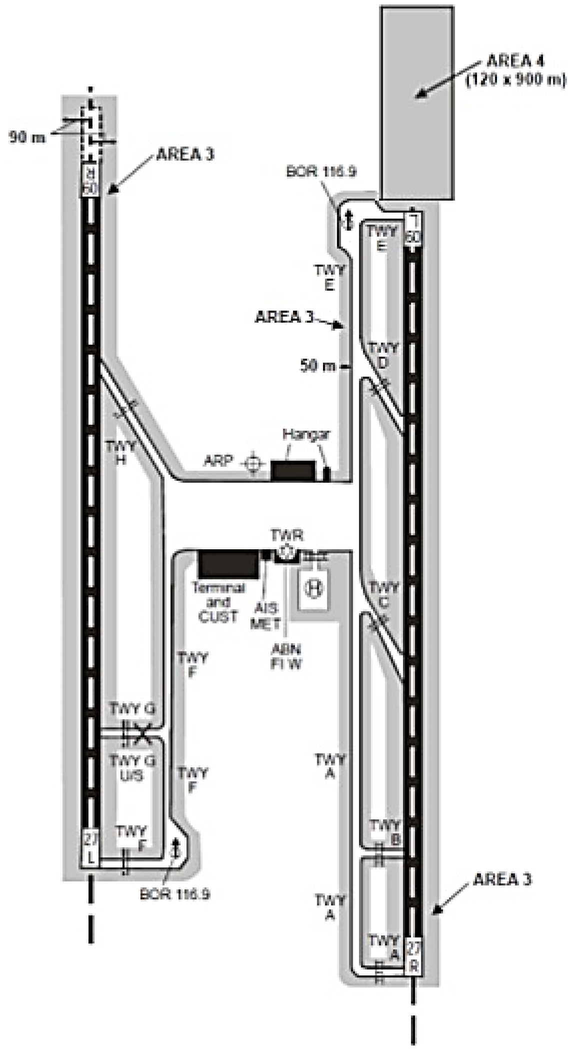


Figure 3.3. Terrain and obstacle data collection surfaces, Area 3 and Area 4

3.1.3. Electronic Terrain and Obstacle data

Electronic terrain and obstacle data must meet the requirements according to RACR-AIS [12], Chapter 10 and ICAO Annex 15 to the Chicago Convention [13], Eurocontrol TOD Manual [14] and ICAO Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information [15].

3.1.3.1. Terrain datasets

"Terrain data sets contain the digital representation of the earth's surface, in the form of continuous elevation values at all points of a grid, referenced to a common datum." [12], [13]

Terrain data that needs to be collected shall be specified as follows, based on the terrain data and obstacle collection surfaces:

"Within the area covered by a 10 km radius from the aerodrome reference point, terrain data shall comply with the Area 2 numerical specifications.

In the area between 10 km and the TMA boundary or the 45 km radius from the aerodrome reference point (whichever is smaller), terrain data that penetrates the horizontal *plane at 120 m above the lowest runway elevation shall comply with Area 2 numerical specifications.*

In the area between 10 km and the TMA boundary or the 45 km radius from the aerodrome reference point (whichever is smaller), terrain data that does not penetrate the horizontal plane at 120 m above the lowest runway elevation shall comply with Area 1 numerical specifications.

In those portions of Area 2 where flight operations are prohibited due to very high terrain or other local restrictions and / or regulations, terrain data shall comply with Area 1 numerical specifications.

For aerodromes regularly used by international civil aviation, electronic terrain data shall be provided for Area 4 for all runways where precision approach Category II or III operations have been established. " [12], [13]

3.1.3.2. Obstacle datasets

Obstacle datasets shall comprise the spatial representation, relative to a common datum, of natural or artificial obstacles, fixed or mobile, permanent or temporary, which penetrate the obstacle limiting surfaces, by points (antennas, poles), lines (power lines) or polygons (buildings).

Obstacle data that needs to be collected shall be specified as follows, based on the terrain data and obstacle collection surfaces:

*'**Area 1**: All objects whose height above the ground is 100 m or more.*

***Area 2a**: All objects whose height of 3 m above the nearest runway elevation measured along the runway centerline, or the same elevation as the runway end for those portions related to a clearway.*

***Area 2b**: All objects whose height is higher than 3 m above the ground.*

***Area 2c**: All objects whose height is higher than 15 m above the ground.*

***Area 2d**: All objects whose height is 100 m above the ground or higher.*

In those portions of Area 2 where flight operations are prohibited due to very high terrain or local restrictions and / or regulations, obstacle data shall be collected and recorded in accordance with Area 1 numerical specifications.

***Area 3**: All objects that are within an area extended by 0,5 m above the horizontal plane passing through the nearest point on the aerodrome movement area.*

***Area 4**: For aerodromes regularly used by international civil aviation, electronic obstacle data shall be provided for Area 4 for all runways where precision approach Category II or III operations have been established " [12], [13]*

3.2. Levels of abstraction

The main purpose of a database is to separate the data description from application programs. Therefore, there are three levels of abstraction as follows:

3.2.1. The conceptual model

By conceptualization, the database specifications and the database content are described.

The main types of entities are defined, they are represented by object classes (feature classes), their geometry, attributes, predefined values and the relationships between them (Figure 3.4).

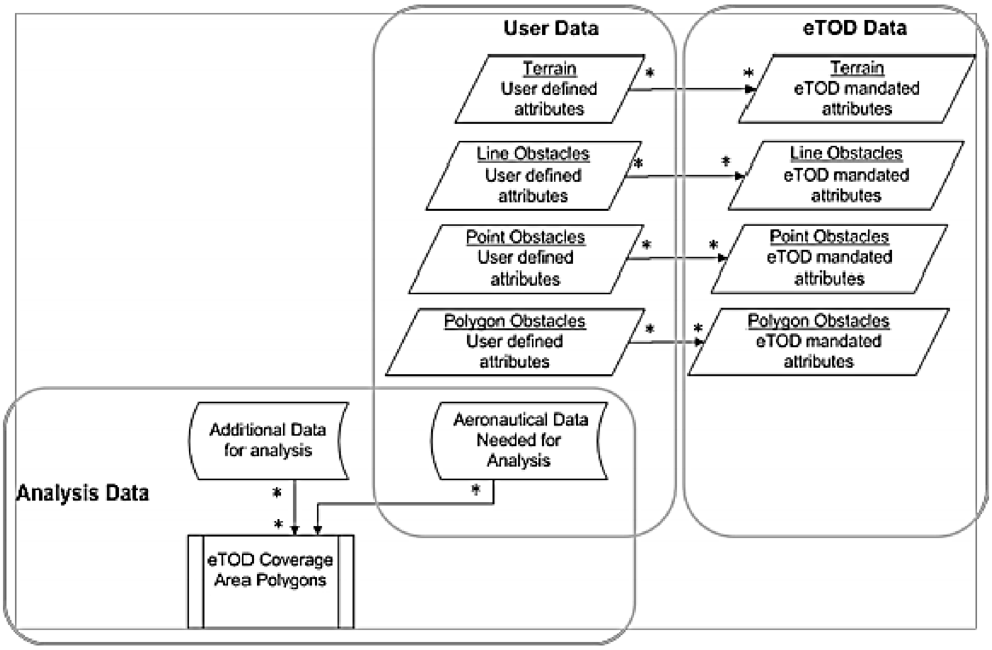


Figure 3.4. eTOD conceptual model [8]

3.2.2. The logical model

The logical model translates the conceptual representation by creating diagrams and lists that describe objects through attributes and the types of interaction between them (Figure 3.5).

This type of modeling is independent from the implementation phase.

UML (*Unified Modeling Language*) is a universal modeling language, a visual modeling tool, which helps creating the database structure in Geodatabase format: Feature Datasets, Feature Classes and tables .

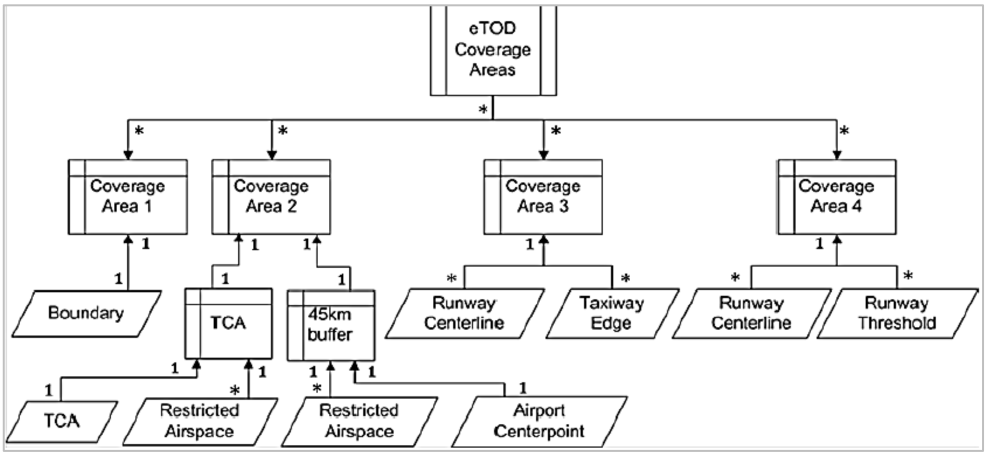


Figure 3.5. The logical model, diagram of eTOD coverage areas and the relationships between these areas [8]

3.2.3. The physical model

The physical model describes the files or tables used to store data, the relationships between object types and the functions that can be performed (Figure 3.6).

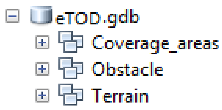


Figure 3.6. The physical model, the database structure

3.3. Metadata

A metadata document is a XML (*eXtensible Mark-up Language*) file that includes the characteristics of a dataset or information related to a resource.

Metadata contains data about the content, quality, or other characteristics of spatial data. An important requirement for the design of a database is having complete descriptions through metadata, at the structure level, content and accuracy of the datasets. [6]

The metadata elements required to determine the location of a dataset include the following (Table 3.3, Table 3.4):

- Identifying the dataset by using a unique code / name within all datasets. Tables with attributes contain unique identification keys, identifiers, which link the attributes (stored in the database) to their geometry, the graphic data.
- Organisation
- The role of the organisation that is responsible for providing the data
- Data collection method
- Spatial reference system
- Frequency area, surface type
- Data quality: resolution, accuracy, integrity
- Date and time
- Maintenance (revision number)
- Traceability

Table 3.3. Terrain data numerical requirements [12], [13], [14], [15]

	Area 1	***Area 2***	***Area 3***	***Area 4***
Post spacing (between 2 successive measured points)	*3 arc seconds (approx. 90 m)*	*1 arc second (approx. 30 m)*	*0.6 arc seconds (approx. 20 m)*	*0.3 arc seconds (approx. 9 m)*
Vertical accuracy	*30 m*	*3 m*	*0.5 m*	*1 m*
Vertical resolution	*1 m*	*0.1 m*	*0.01 m*	*0.1 m*
Horizontal accuracy	*50 m*	*5 m*	*0.5 m*	*2.5 m*
Confidence level	*90%*	*90%*	*90%*	*90%*
Integrity classification	*routine*	*essential*	*essential*	*essential*
Maintenance period	*as required*	*as required*	*as required*	*as required*

Table 3.4. Obstacle data numerical requirements [12], [13], [14], [15]

	Area 1	***Area 2***	***Area 3***	***Area 4***
Vertical accuracy	*30 m*	*3 m*	*0.5 m*	*1 m*
Vertical resolution	*1 m*	*0.1 m*	*0.01 m*	*0.1 m*
Horizontal accuracy	*50 m*	*5 m*	*0.5 m*	*2.5 m*
Confidence level	*90%*	*90%*	*90%*	*90%*
Integrity classification	*routine*	*essential*	*essential*	*essential*
Maintenance period	*as required*	*as required*	*as required*	*as required*

When using metadata, errors may occur or the data may be incomplete, depending on the source. The data provider has the responsibility to provide a description for the available metadata.

Metadata of metadata:

A metadata model defines mandatory or optional metadata and the conditions for mandatory metadata (conditional metadata). [6] (Table 3.5, Table 3.6). This constraint on the occurrence of a metadata element is identified by cardinality.

Table 3.5. Terrain attributes [12], [13], [14], [15]

Terrain attribute	Mandatory / Optional
Area of coverage	*Mandatory*
Data originator identifier	*Mandatory*
Data source identifier	*Mandatory*
Acquisition method	*Mandatory*
Post spacing	*Mandatory*
Horizontal reference system	*Mandatory*
Horizontal resolution	*Mandatory*
Horizontal accuracy	*Mandatory*
Horizontal confidence level	*Mandatory*
Horizontal position	*Mandatory*
Elevation	*Mandatory*
Elevation reference	*Mandatory*
Vertical reference system	*Mandatory*
Vertical resolution	*Mandatory*
Vertical accuracy	*Mandatory*
Vertical confidence level	*Mandatory*
Surface type	*Optional*
Recorded surface	*Mandatory*
Penetration level	*Optional*
Known variations	*Optional*
Integrity	*Mandatory*
Date and time stamp	*Mandatory*
Unit of measurement used	*Mandatory*

Table 3.6. Obstacle attributes [12], [13], [14], [15]

Obstacle attribute	Mandatory / Optional
Area of coverage	*Mandatory*
Data originator identifier	*Mandatory*
Data source identifier	*Mandatory*
Obstacle identifier	*Mandatory*
Horizontal accuracy	*Mandatory*
Horizontal confidence level	*Mandatory*
Horizontal position	*Mandatory*
Horizontal resolution	*Mandatory*
Horizontal extent	*Mandatory*
Horizontal reference system	*Mandatory*
Elevation	*Mandatory*
Height	*Optional*
Vertical accuracy	*Mandatory*
Vertical confidence level	*Mandatory*
Vertical resolution	*Mandatory*
Vertical reference system	*Mandatory*
Obstacle type	*Mandatory*
Geometry type	*Mandatory*

Obstacle attribute	Mandatory / Optional
Integrity	*Mandatory*
Date and time stamp	*Mandatory*
Unit of measurement used	*Mandatory*
Operations	*Optional*
Effectivity	*Optional*
Lighting	*Mandatory*
Marking	*Mandatory*

3.4. Aeronautical data exchange

AIXM (*The Aeronautical Information Exchange Model*) is the XML language used to describe, store, transfer and use of aeronautical information. It allows the standardized coding of aeronautical information and its distribution in a digital format, complying with the Aeronautical Data Quality Requirements (ADQ), to support interoperability within the Single European Sky (SES). [16]

AIXM is fast becoming the global standard for aeronautical data, used by ICAO (International Civil Aviation Organization), FAA (Federal Aviation Administration), NGA (National Geospatial Intelligence Agency), EUROCONTROL (European Organization for the Safety of Air Navigation).

AIXM was developed for the aviation industry to manage the AIXM Conceptual Model by describing the domain of aeronautical information as a collection of features, properties and relationships, using UML and transferring digital data to Aeronautical Information Services (AIS) (AIXM XML Schema). [16]

GM_Curve, GM_Point and GM_Surface classes are used in the AIXM UML model as a basis for an inheritance chain, the relationship between them is shown in the following diagram (Figure 3.7). [16]

AIXM Point or ElevatedPoint classes are used to model the position of aeronautical features, which have point geometry, such as aerodrome reference point (ARP). [16]

AIXM Curve or ElevatedCurve classes are used to model the horizontal extension of aeronautical features, which have line / curve geometry, such as VerticalStructure (Obstacle). [16]

AIXM Surface or ElevatedSurface classes are used to model the horizontal boundaries of aeronautical features, which have surface geometry, such as VerticalStructure (Obstacle). [16]

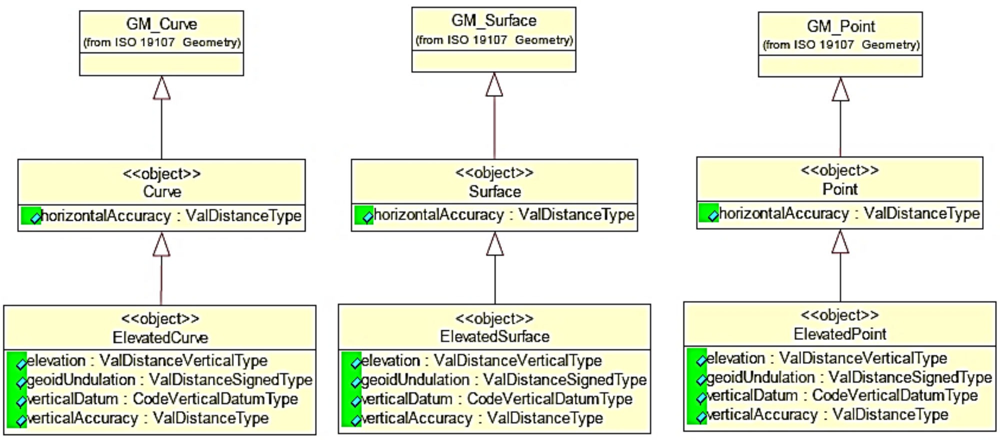


Figure 3.7. Class diagram in UML, AIXM [16]

This model is required in the aviation industry due to the growing need of consistent, quality and updated aeronautical information, which can only be achieved through automation. [16]

AIXM has the following advantages:

- A common language for describing aeronautical information for computer interpretation, but also easy to read by the user for the purpose of development, validation or verification.
- Enhanced safety through improved data integrity and timeliness
- Cost reduction by reusing the data model and enhancing data quality control and integration. [16]

3.5. Existing solutions for aeronautical information systems

In order to meet emerging needs and ensure safe operations, it is desired to improve workflows and data management for air navigation planning. Thus, the need for complex information systems that host global spatial data, by adopting procedures to support coordination between states, would increase the frequency of data updates and at the same time optimize daily work.

Some of the existing solutions are presented:

3.5.1. ESRI platform - ArcGIS for Aviation extension for ArcGIS Desktop

Supporting the particular needs of this industry, ESRI (Environmental Systems Research Institute) has developed **Aeronautical Solution**, an ArcGIS extension, grouped in **ArcGIS for Aviation: Charting** and **ArcGIS for Aviation: Airports**, optimized for creating, visualizing, analyzing, updating and managing aeronautical datasets, exchanging aeronautical information and also creating and maintaining aeronautical charts.

The Desktop extensions ArcGIS Data Interoperability, ArcGIS Workflow Manager, ArcGIS Spatial Analyst and ArcGIS 3D Analyst allow complex spatial data analysis.

The ArcGIS Airports package includes:

- ICAO standards;

- Data validation (Figure 3.8);

- Workflow-based operations (Figure 3.9);

- Information transfer in digital format, updating and management, as well as ensuring traceability;

- Tools for automatic obstacle identification (Figure 3.10);

- Workflow modeling, 3D analysis (Figure 3.11);

- Predefined products: aeronautical charts templates

- AIXM format for data exchange.

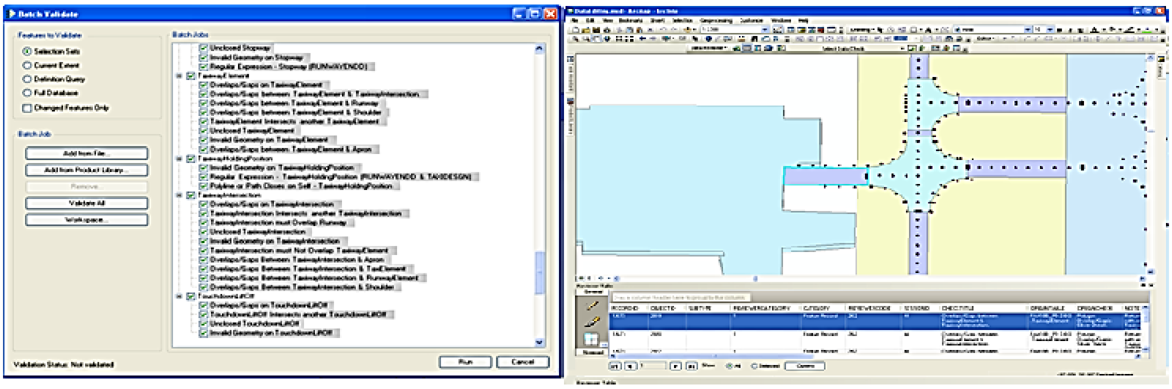


Figure 3.8. Data validation [17]

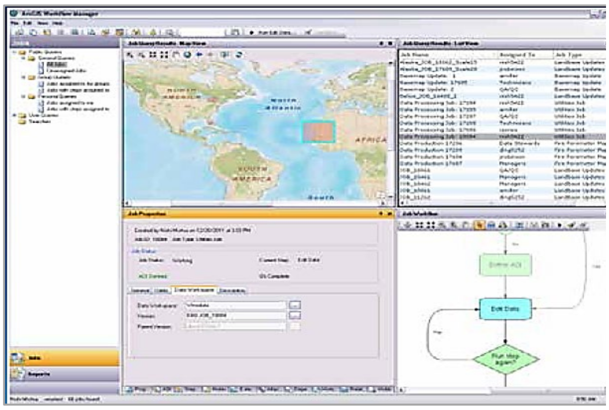
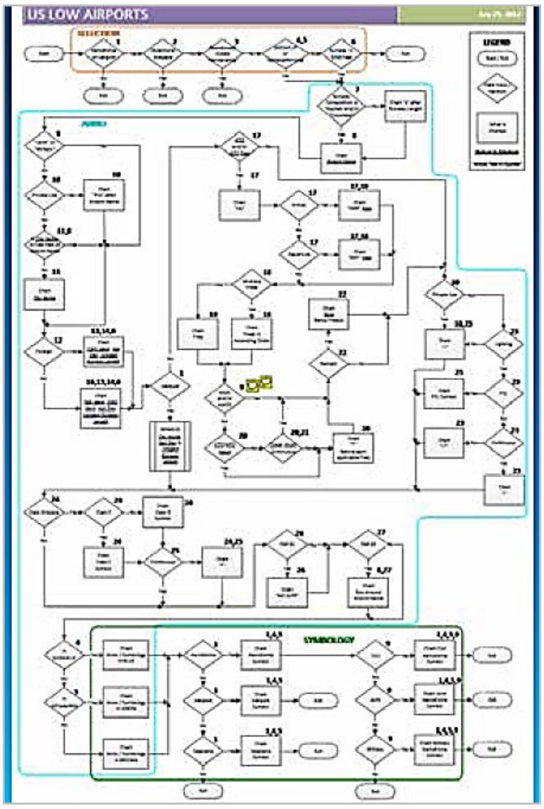


Figure 3.9. Workflow Manager [17]



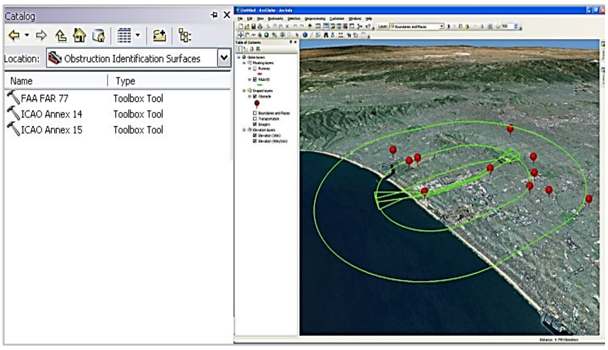


Figure 3.10. Spatial analysis for obstacles identification [17]

ESRI has implemented **eTOD (electronic Terrain and Obstacle Database)** in the AIS model schema, by creating object classes in the workflow: *PointObstacle*, *LineObstacle, PolygonalObstacle* and *ObstacleArea*, along with relation classes*, PointObstacleArea, LineObstacleArea and PolygonalObstacleArea*.

The **Production Line Tool Set (PLTS)** for ArcGIS Aeronautical Solution is designed to increase eTOD efficiency.

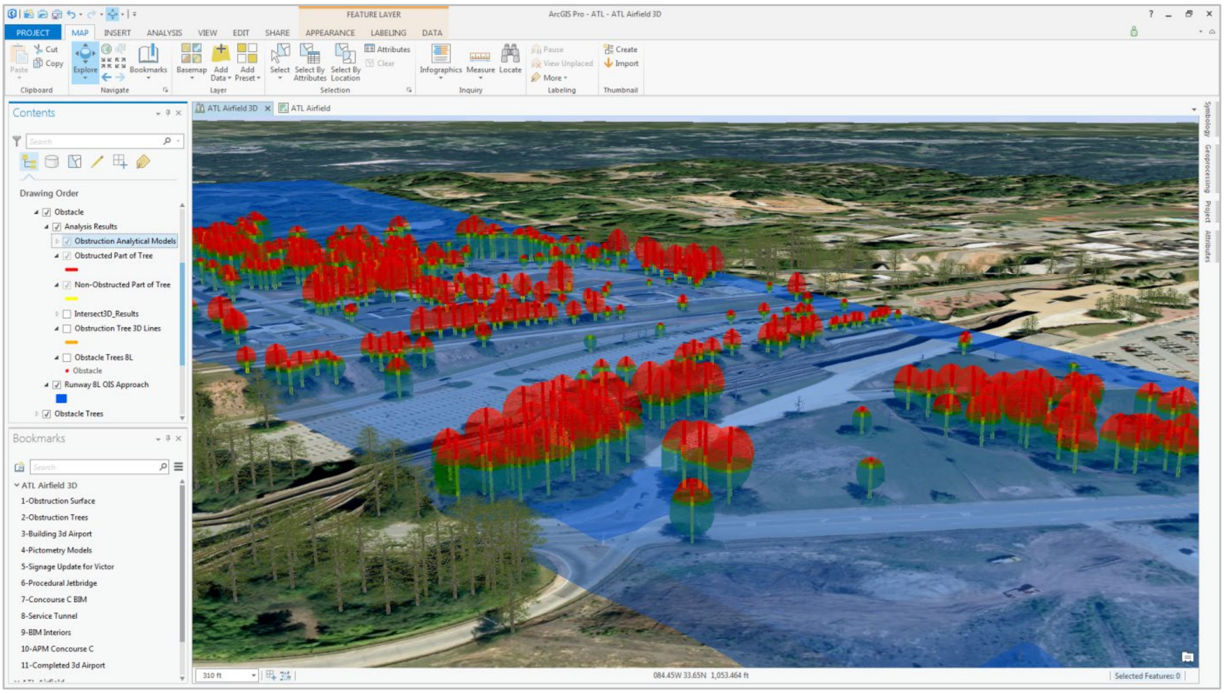


Figure 3.11. Spatial analysis using ArcGIS Pro to test obstacles [17]

ESRI Online Flex application allows publishing the analysis for OIS surfaces and identifying obstacles (Figure 3.12) using web services.

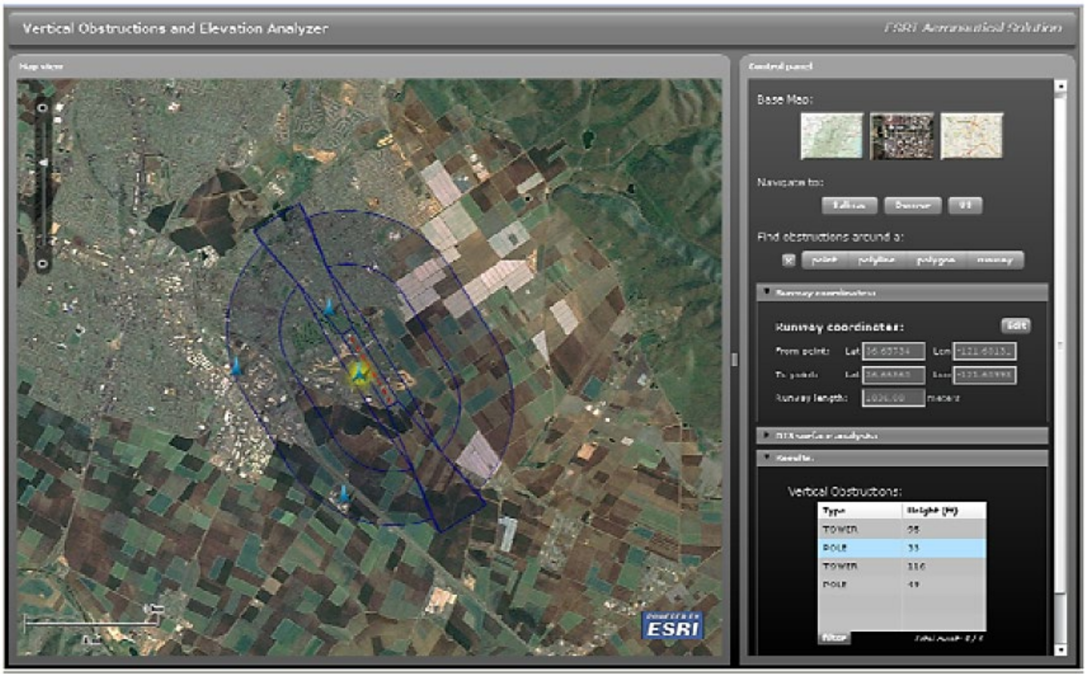


Figure 3.12. Obstacle analysis published in Online Flex as web services [17]

The ICAO portal, **electronic Air Navigation Planning (eANP)** provides authorized users with the ability to import, store, manipulate and analyze aeronautical data for air navigation planning purposes on an ICAO server (Figure 3.13).

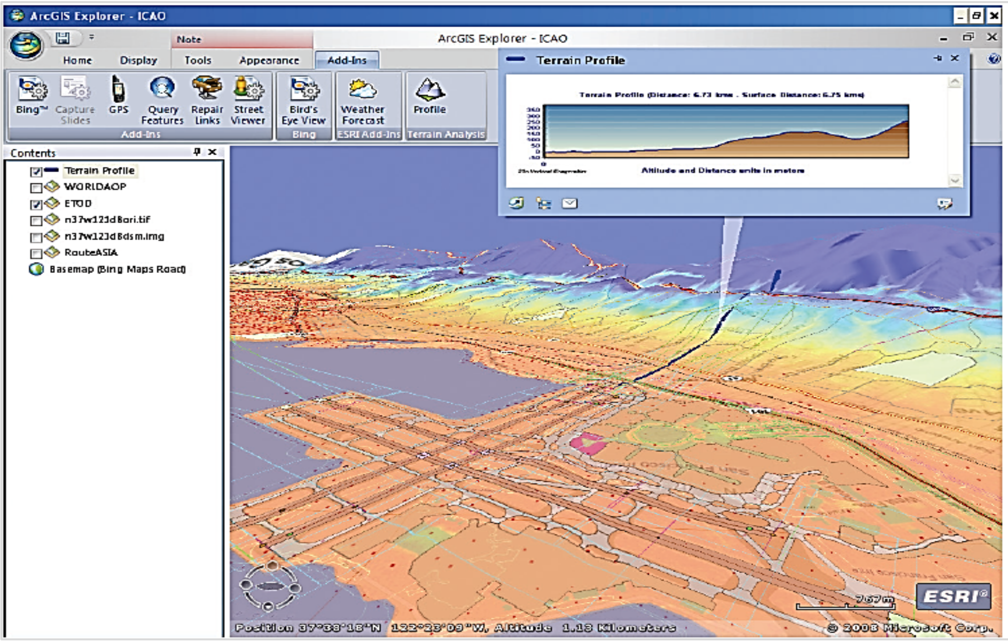


Figure 3.13. eANP interface [17]

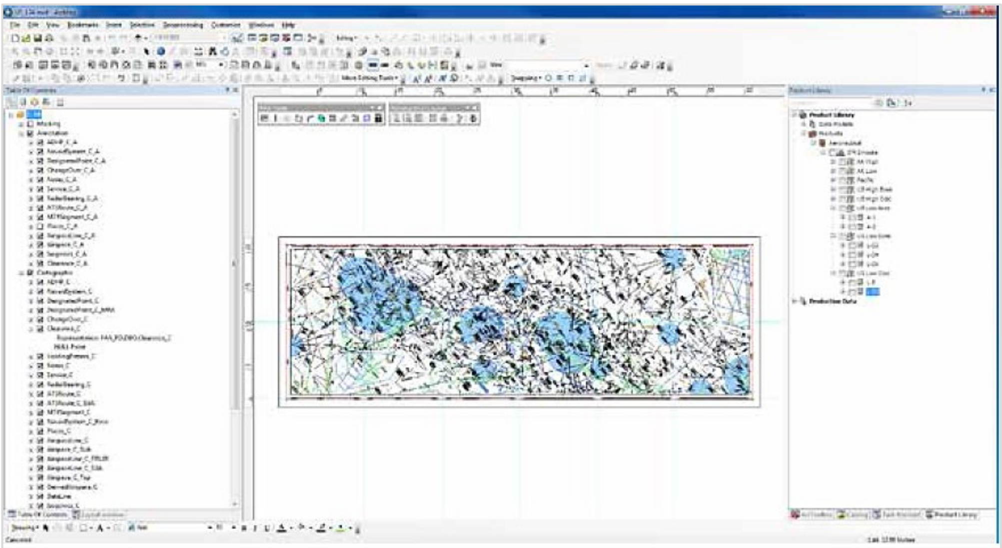


Figure 3.14. Aeronautical charts production using templates [17]

3D Aerodromes product offers the software technology and workflow processes for integrating remote sensing data, terrain and obstacle data, as well as CAD data, in a GIS environment, by using the ArcGIS for Aviation extension, to create and maintain digital aeronautical datasets, as well as manage all information and data processes (Figure 3.14).

3.5.2. IDS Platform - eTOD Suite

The IDS platform developed by INGEGNERIA DEI SISTEMI, offers solutions and services including design, analysis, data management and data exchange:

- Electronic terrain and obstacle data management (eTOD Airport and Obstacle Data Management), including the AIXM 5.1 data exchange format

- Aeronautical information and management services in accordance with ICAO data quality requirements
- The transition from Aeronautical Information Services (AIS) to Aeronautical Information Management (AIM)
- Data traceability
- Flight procedures and airspace design
- Development and validation of operational procedures
- GIS Aeronautical Charting and Aeronautical Information Publications (AIP) and Web Services
- Electromagnetic 3D modeling tools for communications, navigation and surveillance
- Real-time operational evaluation by control tower and cockpit simulator

IDS' **eTOD suite** provides tools for managing terrain and obstacle data, meeting the quality requirements. Its main functionalites include data management, reporting and processing, modeling airport surfaces and creating ICAO obstacle charts.

eTOD includes four products that can be used individually or in combination:

- eTOD Data Manager
- eTOD Airport Data Analyzer
- eTOD Obstacle Chart Builder
- eTOD Obstacle Permission Manager

eTOD Data Manager provides all the tools needed to import, integrate, manage and deliver aeronautical information, terrain data and obstacle data, in accordance with ICAO Annex 15 [13]. At the same time, it imports and validates different types of data, such as: DTM, DSM, orthophotoplans, raster files, vector files. The information is imported into the AIXM data model, which adds predefined values where attributes are missing. (Figure 3.15, Figure 3.16, Figure 3.17).

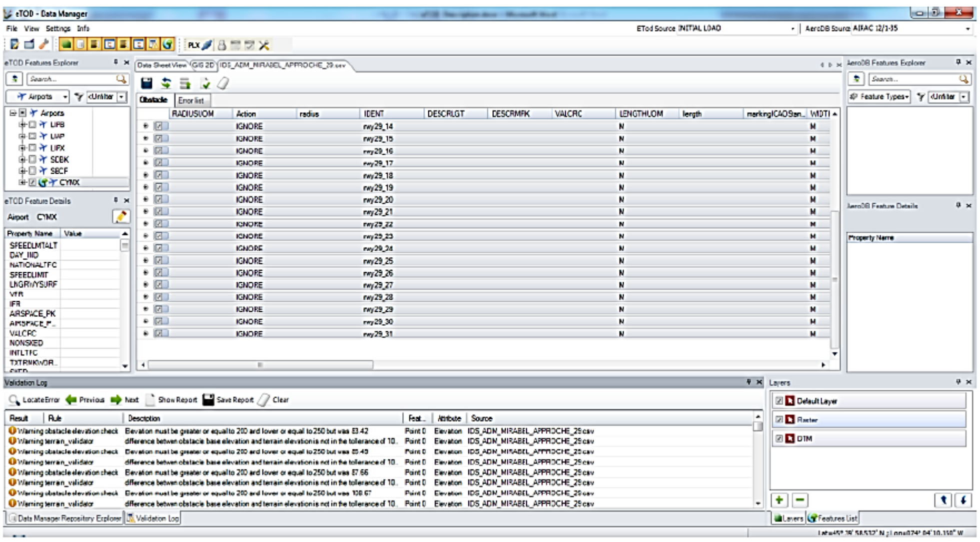


Figure 3.15. Data validation interface [18]

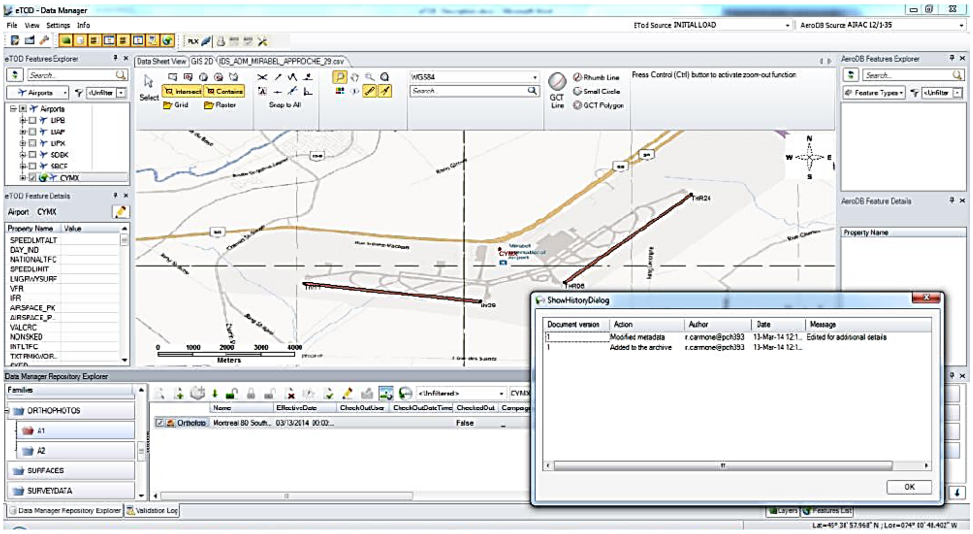


Figure 3.16.eTOD Data Manager Interface [18]

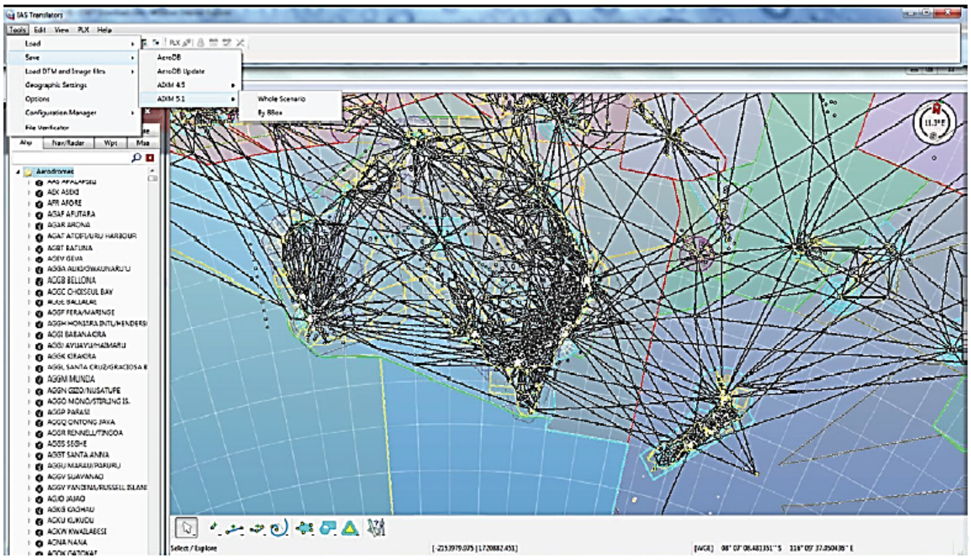


Figure 3.17. Import into AIXM [18]

eTOD Airport Data Analyzer, designed on a GIS / CAD platform, allows the user to load data related to runways, taxiways, aprons, vertical structures, built surfaces, control points, obstacles and terrain to analyze them against obstacle limiting surfaces (Figure 3.18) .

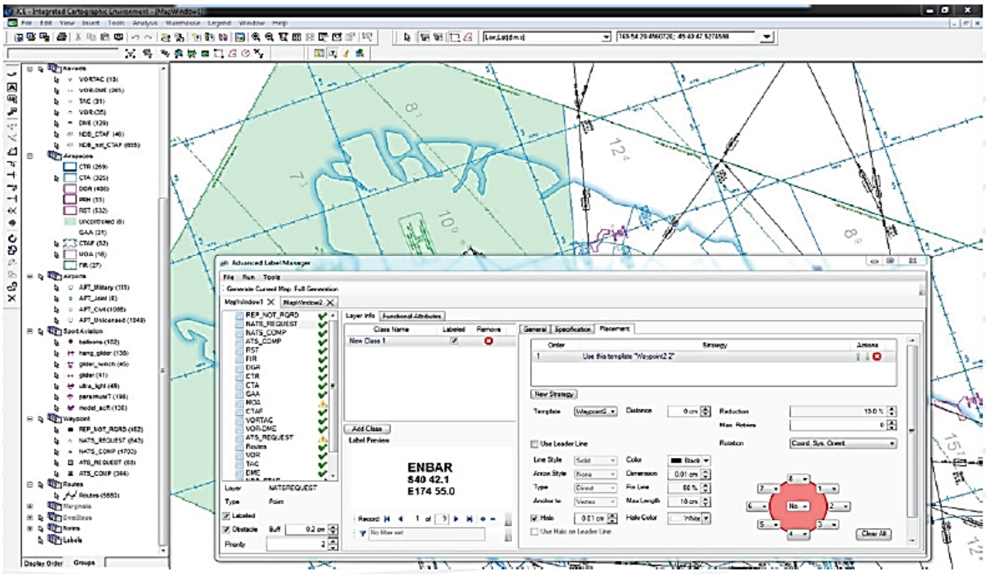


Figure 3.18. eTOD Airport Data Analyzer Interface [18]

eTOD Obstacle Permission Manager is the eTOD subsystem designed for managing processes in order to identify, plan, measure and publish obstacles. Obstacle owners who want to build, resize or remove an existing obstacle can submit a request using the web application. Using this web application, the user finds out if his application has an impact on aeronautical operations and if an aeronautical approval is required.

eTOD Obstacle Chart Builder allows extracting the necessary information for creating ICAO aeronautical charts and allows the user to define templates in a graphic environment.

4. Conclusion

Spatial data management has been a complex task due to the high volume of data and its various sources, therefore the implementation of an aeronautical information system and data integration for complex analysis and validation is a great benefit also for future developments.

After researching and analyzing the existing solutions, I have identified certain aspects that can be improved.

In order to obtain accurate results after applying the specific processing algorithms developed within any application or platform, with data quality in mind, a series of steps for pre-processing spatial data is considered. Optimizing and standardizing this process leads to consolidating and streamlining the entire workflow.

The use of aeronautical information systems ensures the quality of aeronautical data and information and data exchange for sustainable growth.

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