

**MINISTRY OF EDUCATION  
TECHNICAL UNIVERSITY OF CIVIL ENGINEERING OF BUCHAREST  
FACULTY OF GEODESY**

**DOCTORAL THESIS  
SUMMARY**

**CONTRIBUTIONS TO GEODETIC WORKS IN  
THE AVIATION INDUSTRY USING MODERN  
METHODS AND TECHNOLOGIES**

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### List of abbreviations

|             |                                                       |
|-------------|-------------------------------------------------------|
| AACR        | RCAA/ Romanian Civil Aeronautical Authority           |
| ADQ         | Aeronautical Data Quality                             |
| AGL         | Above Ground Level                                    |
| AIM         | Aeronautical Information Management                   |
| AIP         | Aeronautical Information Publication                  |
| AIS         | Aeronautical Information Services                     |
| AISP        | Aeronautical Information Services Provider            |
| AIXM        | Aeronautical Information Exchange Model               |
| AMDB        | Aerodrome Mapping Database                            |
| AMSL        | Above Mean Sea Level                                  |
| AMXM        | Aerodrome Mapping Exchange Model                      |
| AOI         | Area of interest                                      |
| ARP         | Aerodrome Reference Point                             |
| ASDA        | Accelerate-Stop Distance Available                    |
| A-SMGCS     | Advanced Surface Movement Guidance and Control System |
| CAA         | Civil Aviation Authority                              |
| CWY         | Clearway                                              |
| EASA        | European Aviation Safety Agency                       |
| eTOD        | Electronic Terrain and Obstacle Data                  |
| EUROCAE     | European Organisation for Civil Aviation Equipment    |
| EUROCONTROL | European Organisation for Safety of Air Navigation    |
| FAA         | Federal Aviation Administration                       |
| GIS         | Geographic Information System                         |
| GCP         | Ground Control Points                                 |
| GSD         | Ground Sample Distance                                |
| IATA        | International Air Transport Association               |
| ICAO        | International Civil Aviation Organisation             |
| LDA         | Landing Distance Available                            |
| MSL         | Mean Sea Level                                        |
| NATS        | National Air Traffic Services                         |
| OFZ         | Obstacle Free Zone                                    |
| OIS         | Obstacle Identification Surface                       |
| OLS         | Obstacle Limitation Surfaces                          |
| PANS-OPS    | Procedures for Air Navigation Services                |
| PBN         | Performance Based Navigation                          |
| RESA        | Runway End Safety Area                                |
| RWY         | Runway                                                |
| SWY         | Stopway                                               |
| THR         | Threshold                                             |
| TIN         | Triangulated Irregular Network                        |
| TIXM        | Terrain Information Exchange Model                    |
| TMA         | Terminal Manoeuvring Area /Terminal Control Area      |
| TODA        | Take-off Distance Available                           |
| TORA        | Take-off Run Available                                |
| TWY         | Taxiway                                               |

|     |                            |
|-----|----------------------------|
| UAV | Unmanned Aerial Vehicle    |
| UML | Unified Modelling Language |
| XML | Extensible Markup Language |

## Chapter 1. Introductory aspects

In the current climate of growing urbanisation worldwide, the United Nations published a study in 2018 [1] estimating that 55% of the world population is concentrated in urban areas, reaching 68% by 2050 and also estimated global population growth with another 2.5 billion inhabitants by 2050. These factors lead to the need of streamlining spatial planning for strategic development.

Given the location of airports near or embedded in large cities, an aeronautical information system is needed to effectively manage the dynamics of the urban environment using fast and accurate methods of visualizing and analyzing geospatial information.

An aeronautical information system uses the information obtained from aeronautical studies, carried out for digital rendering of terrain and obstacles related to the protected airspace, for a better understanding of the environment around airports, thus leading to enhancing the safety of operations, securing the environment in which aircrafts move, as well as support for ground and aircraft applications.

Aeronautical studies describe the conditions, restrictions and obligations imposed or recommended by national and international civil aviation regulations for the identification, assessment and control of obstacles, by defining the protection surfaces and the maximum height limits for the structures' development in the airport's perimeter so as they do not infringe the obstacle limitation surfaces.

Ensuring the safe conduct of operations on the ground as well as in the airspace, is attained by using the aeronautical information and results obtained from the aeronautical studies, in the process of designing the flight procedures, design and technical operation of airport infrastructure.

Conducting aeronautical studies includes the use of several specialized computer programs and tools and the participation of a number of entities and institutions (Civil Aeronautical Authorities, aerodrome operators, airlines, Air Traffic Services Providers, etc.) in the life cycle of the aeronautical data and information, a process that requires interoperability and standardization of aeronautical data exchange and collaboration and communication between all stakeholders.

These aspects generate high costs and a long time for the development and completion of the projects.

The aim of this research is to enhance the methods of implementing and conducting aeronautical studies by automating processes, workflows and integrating spatial information into a centralised database, facilitating the access to aeronautical information for all departments that are involved and thus ensuring data exchange in a standardized format.

The objectives of the research include:

- obtaining digital terrain models using modern technologies for spatial data acquisition and processing;
- application of remote sensing techniques for change detection, in order to reduce maintenance operations;
- testing various solutions for the aviation industry and identifying the particular needs for this industry;

- implementation of GIS system for the aviation industry including eTOD (electronic Terrain and Obstacle Data) and AMDB (Aerodrome Mapping Database) in a centralised database;
- creating data models by automating the processes for designing obstacle identification surfaces;
- ensuring the accessibility of the data models;
- streamlining the methods of updating and producing aeronautical charts;
- delivering services and solutions by accessing the GIS system;
- reducing execution costs and quality control checks by automating processes.

This doctoral thesis is structured in seven chapters, as follows:

**Chapter 1 - Introductory aspects** includes an overview on aeronautical studies, the individuality and complexity of these works, as well as the aim and objectives of the research.

**Chapter 2 – Coordinate reference systems** contains general considerations on coordinate reference systems, reference systems for altitudes and coordinate transformations. These are necessary for modeling geodetic observations as functions of unknown parameters of interest.

**Chapter 3 - State of the art of aeronautical studies** presents the need for information systems for the aviation industry, which include high-precision digital models, the identification of obstacles to ensure the safety of operations and the distribution of interoperable products.

**Chapter 4 - Spatial data used in aeronautical information systems** presents two case studies where I used geospatial data acquired using remote sensing techniques; the first case study expands on change detection for the protection surfaces around airports, using SAR satellite imagery, as well as optical imagery, and in the second case study the steps taken to process optical satellite images in order to obtain digital terrain models and orthomosaics, to extract 3D information and integrate the results into GIS.

**Chapter 5 – Aeronautical information systems** presents the types of database entities, the structure of the database, aeronautical data exchange as well as an analysis and case studies of the platforms and applications that offer solutions for this industry, and the testing results.

**Chapter 6 - Integration of eTOD aeronautical studies and AMDB (Aerodrome Mapping Database) into a centralised database** describes the personal contributions to enhancing the aeronautical studies by automating processes and 3D modeling of the protection surfaces around airports and integration of aeronautical information into a centralised database.

**Chapter 7 - Conclusions** presents the general conclusions of the research, the original contributions, as well as perspectives on extending the research.

## Chapter 2. Coordinate reference systems

### 2.1. General considerations on coordinate reference systems

During this research, I used several datasets describing data in various coordinate reference systems used in several countries, from Europe, the Middle East and Africa, which require knowing the parameters and algorithms for transforming the coordinates to a common reference system, WGS-84.

➤ In the United Kingdom, the following coordinate systems and parameters are used:

- The British National Grid coordinate system that adopts the Transverse Mercator projection, with the following parameters:
  - The origin of the system has the following geographical coordinates:
    - Latitude  $B_0 = 49^\circ$  N (Latitude of Origin)
    - Longitude  $L_0 = 2^\circ$  W (Central Meridian)
  - The coordinates of the origin in the Projection System:
    - $E_0 = 400000$  m (False Easting)
    - $N_0 = -100000$  m (False Northing)
  - Scale Factor  $F_0 = 0.9996012717$
- OSGB36 datum (Ordnance Survey Great Britain 1936) based on Airy 1830 Ellipsoid and the related parameters:
  - semi-major axis  $a = 6377563,396$  m
  - semi-minor axis  $b = 6356256,909$  m
  - flattening  $f = 1 / 299,3249646$

To some extent, distortions in the traditional OSGB36 triangulation network are inevitable. As it is not possible to use a single set of coordinate transformation parameters across the country, different local transformations are required. For this reason, the transformation between ETRS89 and OSGB36 is not a standard Helmert transformation. Therefore, it is necessary to determine the local transformation parameters in order to obtain the coordinate conversion.

Ordnance Survey has developed a transformation called The National Grid Transformation [2].

The transformation model between ETRS89 and OSGB36, called OSTN15 (Ordnance Survey National Grid Transformation) is used for planimetric coordinates. It applies to geographical coordinates using independent parameters that must be calculated for both latitude and longitude. The OSTN15 transformation consists of a grid of 700 km on 1250 km of translation vectors, at a resolution of 1 km, covering the entire surface of Great Britain. The transformation parameters of a given point are calculated by bi-linear interpolation from the parameters of the corners of the 1 km subcell in which the point is located.

At the same time, the transformation model between ellipsoidal and orthometric altitude ETRS89 - ODN (Ordnance Datum Newlyn) or vertical national datum is used, called the OSGM15 geoid model (Ordnance Survey Geoid Model).

The ODN reference surface is a local model of the optimized geoid, with zero point in Newlyn, Cornwall.



Figure 2.1. Diagram of coordinate transformations

A transformation between datums is performed and then the conversion between the OSGB36 datum to the British National Grid Coordinate System - Transverse Mercator projection (UKTM) (Figure 2.1).

The planimetric coordinates in the OSGB36 system are determined using the OSTN15 model, and the orthometric altitude is determined using the OSGM15 geoid model; the coordinate transformation program provided by Ordnance Survey is used [3].

➤ In the United Arab Emirates, the Emirate of Dubai uses both the DLTM (Dubai Local Transverse Mercator) coordinate system and UTM, zone 40, northern hemisphere, which are based on WGS-84 ellipsoid.

- The DLTM coordinate system is adopted by the Municipality of Dubai, with the following parameters:

- The origin of the system has the following geographical coordinates:
  - Latitude  $B_0 = 0^\circ$  N (Latitude of Origin)
  - Longitude  $L_0 = 55^\circ 20'$  E (Central Meridian)
- Origin coordinates in the Projection System:
  - $E_0 = 500000$  m (False Easting)
  - $N_0 = 0$  m (False Northing)
- Scale Factor  $F_0 = 1.0$

- UTM coordinate system, zone 40, northern hemisphere, with the following parameters:

- The origin of the system has the following geographical coordinates:
  - Latitude  $B_0 = 0^\circ$  N (Latitude of Origin)
  - Longitude  $L_0 = 57^\circ$  E (Central Meridian)
- The coordinates of the origin in the Projection System:
  - $E_0 = 500000$  m (False Easting)
  - $N_0 = 0$  m (False Northing)
- Scale factor  $F_0 = 0.9996$

➤ In the United Arab Emirates, in the Emirate of Ras Al-Khaimah, the coordinate system is UTM, zone 40, Northern Hemisphere, which is based on WGS-84 ellipsoid.

➤ In Cameroon, the coordinate system is UTM, zone 32, northern hemisphere, which is based on WGS-84 ellipsoid.

- The origin of the system has the following geographical coordinates:
  - Latitude  $B_0 = 0^\circ$  N (Latitude of Origin)
  - Longitude  $L_0 = 9^\circ$  E (Central Meridian)
- The coordinates of the origin in the Projection System:

- $E_0 = 500000$  m (False Easting)
- $N_0 = 0$  m (False Northing)
- Scale factor  $F_0 = 0.9996$

## **2.2. Altitude reference systems**

In the UK, the national reference system for altitudes is the Ordnance Datum with the reference point at Newlyn, Cornwall.

In the United Arab Emirates, the Emirate of Dubai uses EGM2008 as reference for altitudes, and in the Emirate of Ras Al Khaimah, EGM96 is used as reference for altitudes.

In Cameroon, EGM96 is used as reference for altitudes.

## **2.3. Coordinate transformations**

## **Chapter 3. State of the art of aeronautical studies**

### **3.1. The current international situation: orientations, priorities, directions, objectives, existing knowledge in the field of study**

The ICAO Strategy, Global Air Navigation Plan 2016-2030 (GANP) [4] whose purpose is to ensure continuity and harmonization of aeronautical data, guides all ICAO state members to implement performance-based navigation.

Performance Based Navigation (PBN) implementation [5] which uses GNSS technology, supports efficient airspace design and systematization of air traffic routes, using advanced aircraft navigation capabilities (RNAV). It also helps reducing the impact on the environment, increasing the capacity and enhancing safety by identifying obstacles.

In order to support GANP objectives [6], the following datasets are necessary:

- Quality assured aeronautical information
- Automation of aeronautical information services (AIS) in terms of data management, processing, verification, use and exchange
- Digital datasets for aeronautical information publication - AIP
- Terrain datasets
- Obstacle datasets
- Aerodrome Mapping Datasets for international airports
- IFP - Instrument Flight Procedures datasets.

The individuality of aeronautical studies leads to particularization of the methods of acquisition and processing of spatial data, adapting the workflows to the purpose of the applications.

An AMDB (Aerodrome Mapping Database) is produced using various data sources: GNSS data, digital terrain models and high resolution orthomosaics that can be derived from photogrammetric flights with UAV platforms, remote sensing imagery or LiDAR data. Due to the small area of interest (airport perimeter) and taking into account the costs of the project, the photogrammetric methods are the optimal choice for data collection, however for international airports where air traffic does not allow operating a UAV platform or surveying GCP, in order to avoid any impact on operations, the optimal choice for collecting data in order to create an AMDB is through remote sensing imagery [7],[8].

This research project aims to enhance the methods of conducting aeronautical studies and the production and updating of aeronautical charts, in order to maintain aviation safety, as part of the design and technical operation of aerodromes, by implementing a GIS centralised database that includes an aeronautical information system, as well as an aerodrome mapping database, thus allowing access to aeronautical information through interoperable services.

### 3.1.1. The American framework

### 3.1.2. The European framework

## 3.2. The current national situation

There are currently 16 international airports near major cities in Romania, the following classification is according to the number of passengers [9] that were registered in the first quarter of 2019 (Table 3.1):

Table 3.1. International airports in Romania, classified according to the number of passengers in the first quarter of 2019

| Nr. | City              | Airport                                   | ICAO code |
|-----|-------------------|-------------------------------------------|-----------|
| 1   | București Otopeni | Henri Coandă International Airport        | LROP      |
| 2   | Cluj-Napoca       | Avram Iancu International Airport         | LRCL      |
| 3   | Timișoara         | Traian Vuia International Airport         | LRTR      |
| 4   | Iași              | Iași International Airport                | LRIA      |
| 5   | Sibiu             | Sibiu International Airport               | LRSB      |
| 6   | Craiova           | Craiova International Airport             | LRCV      |
| 7   | Suceava           | Stefan cel Mare International Airport     | LRSV      |
| 8   | Bacău             | George Enescu International Airport       | LRBC      |
| 9   | Târgu Mureș       | Transilvania International Airport        | LRTM      |
| 10  | Oradea            | Oradea International Airport              | LROD      |
| 11  | Constanța         | Mihail Kogălniceanu International Airport | LRCK      |
| 12  | Satu Mare         | Satu Mare International Airport           | LRSM      |
| 13  | Baia Mare         | Maramureș International Airport           | LRBM      |
| 14  | București Băneasa | Aurel Vlaicu International Airport        | LRBS      |
| 15  | Arad              | Arad International Airport                | LRAR      |
| 16  | Tulcea            | Delta Dunării International Airport       | LRTC      |

These are EASA certificated aerodromes according to Reg. (EU) 139/2014 [10].

Among the operational airfields, the list of certificated civil airfields [11], as follows (Table 3.2):

Table 3.2. Certificated airfields in Romania

| Nr. | City        | Airfield                           | ICAO code |
|-----|-------------|------------------------------------|-----------|
| 1   | Caransebeș  | Banat - Caransebeș                 | -         |
| 2   | Tuzla       | Tuzla                              | LRTZ      |
| 3   | Sibiu       | Măgura                             | LRCD      |
| 4   | Brașov      | Sânpetru                           | LRSP      |
| 5   | Ploiești    | Gheorghe Valentin Bibescu Ploiești | LRPW      |
| 6   | Cluj-Napoca | Dezmir - Cluj                      | -         |
| 7   | Arad        | Charlie-Bravo Șiria                | LRCB      |
| 8   | Târgu-Mureș | Mureșeni                           | LRMS      |
| 9   | Iași        | Iași Sud                           | LRIS      |
| 10  | Craiova     | Craiova - Sud                      | LRCW      |
| 11  | Pitești     | Geamăna                            | LRPT      |
| 12  | Deva        | Săulești Constantin Manolache      | LRDV      |
| 13  | București   | Climeni                            | LRCN      |
| 14  | Baia Mare   | Tăuții-Magheruș                    | -         |
| 15  | Bistrița    | Bistrița                           | LRBN      |

The National Strategy for Sustainable Development of Romania [12] is a project for the development of intermodal transport, which ensures a fast connection between different means of transport, by air, by rail and road.

Romania is also part of SPICE project [13] (Synchronized PBN Implementation - Cohesion Europe) which is co-financed by the European Union Interconnection Mechanism and coordinated by EUROCONTROL, which is part of the implementation phase of SESAR (Single European Sky) program, installation of PBN procedures, equipping aircraft with PBN capabilities and development of air navigation infrastructure.

During 2016, the first ICAO compliant project for implementing eTOD database (electronic Terrain and Obstacle data) for Iași International Airport was delivered to the Romanian Civil Aeronautical Authority (AACR). Several other projects followed, such as eTOD for Maramureș International Airport, Baia Mare International Airport and in 2017 Henri Coandă International Airports, Bucharest Otopeni and Aurel Vlaicu, Bucharest Băneasa [14], projects where I participated through implementation and development, whilst working at SC Cornel & Cornel Topoexim SRL.

Bucharest Airports National Company uses the geospatial information contained in these databases for the following two airports, LROP and LRBS, in order to design the PBN procedures, as part of SPICE project.

For conducting the aeronautical studies and creating the aeronautical and obstacle charts for Maramureș International Airport, Baia Mare [15], a combination of photogrammetric UAV methods and classical determinations was used to collect the geospatial data. Geodetic works were also carried out, to collect GNSS data in order to determine the GCP for the photogrammetric flight. The derived digital terrain models have the vertical accuracy of  $\pm 7$  cm and the high-resolution orthomosaic with a horizontal accuracy of  $\pm 3$  cm. The derived products are used to assess and identify obstacles.

Conducting aeronautical studies in order to attain the certification or authorization of aerodromes, designing and technical operation of aerodromes and heliports are necessary for maintaining and improving standards.

## **Chapter 4. Spatial data used in aeronautical information systems**

### **4.1. Study on change detection for the protection surfaces around airports, using satellite imagery. Case study of Dubai International Airport, United Arab Emirates**

#### ***4.1.1. 3D change detection using SAR satellite imagery***

This study aims to provide a technical solution, by detecting changes in the area of interest, using satellite images collected at different times, to test the 3D development of structures against the protected airspace. The study was conducted in collaboration with L3Harris Geospatial and SLC Geomatic Solutions Ltd.

The need for this study is demonstrated by the need to update aeronautical studies with the frequency and data quality required by ICAO, in an efficient way, both in terms of costs and technological workflows. Given the high costs associated to LiDAR acquisition or remote sensing imagery, these methods of collecting spatial data are less accessible to the vast majority of airports, especially regional ones.

#### **Benefits of the study:**

- Streamlining the analysis process, by identifying areas where changes have occurred, using satellite images collected during consecutive years.
- Reducing processing and analysis costs, considering the dynamics and speed of urban development in relation to the cyclicity of data acquisition.

#### **Objectives:**

This technical approach aims at using satellite images collected by active sensors, in two stages:

- I. In the first instance, the analysis and interpretation of SAR (Synthetic-Aperture Radar) images collected by Sentinel-1 system.
- II. Using the results obtained in the first stage and detecting 3D changes using very high resolution SAR images, collected by TerraSAR-X.

3D information is obtained by exploiting SAR images collected by TerraSAR-X platform, which is operated by DLR - German Aerospace Center and Airbus Defense & Space (EADS Astrium), using interferometry techniques and obtaining digital terrain models and digital surface models.

For the area of interest in this case study, I chose one of the busiest international airports in the world and currently the third hub in the world for international cargo. The results would be very useful in the analysis process, considering the fast pace of the urban development in the Emirate of Dubai.

In the first stage, as input data I used the following satellite scenes collected by Sentinel-1:

- T1 (used as reference) collected in August 2016 on:
  - 2016-08-16
  - 2016-07-23
  - 2016-08-28
- T2 collected in November 2017 on:
  - 2017-11-15

- 2017-11-03
- 2017-11-27

The images were processed using SARscape Analytics Toolbox created by L3Harris Geospatial and Sarmap SA.

SARscape Analytics Toolbox is installed along with SARscape v5.5.3 and ENVI v5.5.3, on a workstation with Windows 10, 64bit operating system.

The input data must have the following properties:

- to be collected by the same sensor: Sentinel-1A
- to have the same acquisition geometry (Ascending or Descending): Ascending
- to have the same incidence angle
- to have the same data type: Product type - SLC (Single Look Complex)
- to have the same polarization: single: HH or VV; or dual: HH + HV or VV + VH, where

HH - radar signal transmitted horizontally, received horizontally

VV - radar signal transmitted vertically, received vertically

HV - radar signal transmitted horizontally, received vertically

VH - radar signal transmitted vertically, received horizontally.

The information derived from the electromagnetic wave includes the propagation direction, wavelength, polarization, amplitude (intensity) and phase information.

One aspect that needs to be mentioned relates to the challenges we're facing when working with SAR data, such as the side-looking geometry of SAR images, geometric distortions caused by relief, foreshortening, layover and shadowing, and speckle noise, especially in urban areas.

Sentinel-1 SLC (Single Look Complex) level 1 products acquired in IW (Interferometric Wide) operating mode have 250 km swath and ground resolution of approximately 5x20 m (single look). [16].

IW SLC products contain a sub-swath image on the polarization channel, so a total of three images for single polarization or six images for dual polarization. Each image contains a series of bursts, where each burst was processed as a separate SLC image.

"SAR Image Geocoding" module, which is part of SARscape Analytics Toolbox, is used for geocoding SAR images in order to derive intensity information.

SLC images are georeferenced using satellite orbit information corresponding to the image acquisition geometry, which can be found in the Sentinel-1 Auxiliary Files on Sentinel-1 quality control website.[17].

Geocoding SAR images is the process where the image is resampled from radar geometry to obtain a product in UTM WGS-84 projection. The geocoding process includes radiometric calibration and normalization of SAR data, geometric calibration using DEM (SRTM 3v4 at 90 m resolution or SRTM 1v3 at 30 m resolution), in this case I used SRTM 3v4.

The output coordinate system is based on the DEM coordinate system, which is UTM, zone 40, northern hemisphere, based on WGS-84 ellipsoid.

The control points (GCP) are determined using GNSS technology, RTK (Real Time Kinematic) method, real-time kinematic measurements using the base-rover system. GCPs are used to evaluate the geolocation accuracy, in this case planimetric accuracy is  $\pm 2$  cm and altimetric accuracy is  $\pm 3$  cm.

The workflow for geocoding SLC SAR images is shown in Figure 4.1.

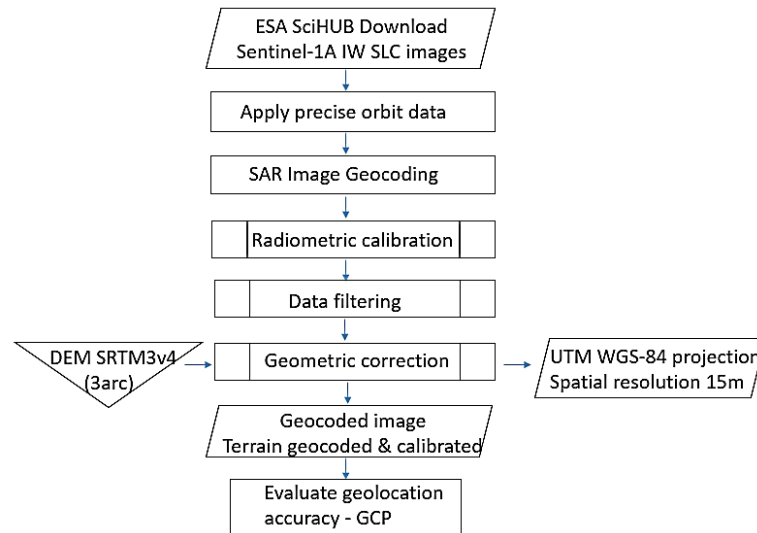


Figure 4.1. Workflow for geocoding SLC SAR images

"SAR Change Detection" module included in SARscape Analytics Toolbox, analyzes the amplitude and phase, information that is derived from SLC images and creates a classification raster that identifies changes between the two images.

This workflow can detect subtle changes in the structure of the scene viewed.

Amplitude analysis uses the intensity of the SAR images to detect temporal changes over time.

Phase analysis uses the coherence or stability index between the scenes input to track changes.

The classification is based on a stability index threshold (interferometric coherence) and on a ratio threshold (between the T2 image intensity and the T1 image intensity).

The ratio provides information on temporal variation of intensity backscatter. Backscatter depends on soil roughness and dielectric constant.

The stability index (interferometric coherence) provides information on elementary scatterers variation at subcell size resolution.

The input data for this workflow is the Sentinel-1 IW SLC image pair (TOPSAR mode). SRTM 3v4 DEM at 90 m spatial resolution is used as reference for orthorectification.

The output data is in UTM coordinate system, zone 40, the Northern Hemisphere, which is based on WGS-84 ellipsoid and the altitudes reference system is EGM96. The result is a raster file at 15 m spatial resolution.

The stability index represents the interferometric coherence threshold and ranges from 0 to 1; where the values close to 1 detects more stable objects, and values close to 0 detects the maximum changes. AS default a value equal to 0.2 is pre-set. This value is

strictly related to typical landscape, temporal baseline between T1 image T1 and T2 image.

The ratio threshold (expressed in dB) between T2 image backscatter value and T1 image backscatter value. As default a value equal to 3 is pre-set. This value is strictly related to typical landscape, temporal baseline between T1 image T1 and T2 image.

The workflow for change detection between geocoded SLC images is shown in Figure 4.2.

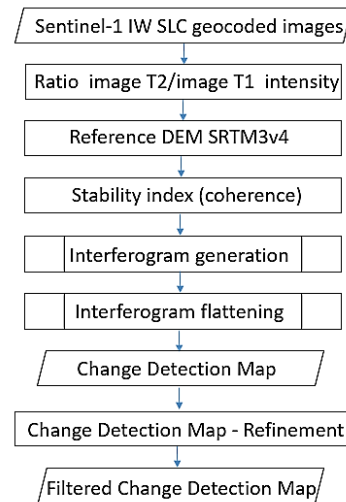


Figure 4.2. Workflow for change detection between two geocoded SLC images

A Change Detection Map is the classification raster that represents the change that occurred in the area of interest, between August 2016 and November 2017. The results are exported to Google Earth Pro for visualization (Figure 4.3).



Figure 4.3. Change detection map - results exported to Google Earth Pro

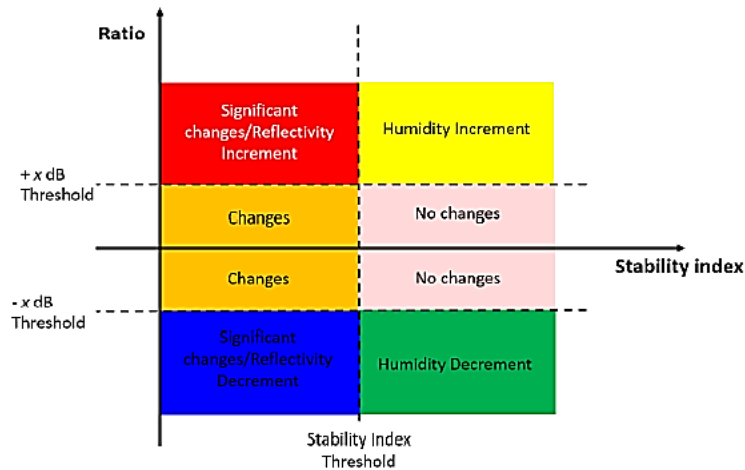


Figure 4.4. Classification key graph

The interpretation and evaluation of the classification raster shown in Figure 4.3 is performed using the graph in Figure 4.4 as follows:

- pink color - no change
- red color - significant changes, reflectivity increment
- blue color - significant changes, reflectivity decrement
- green color – humidity decrement
- yellow color – humidity increment
- orange color – changes at small scale

“SAR Change Detection - Classification Refinement” module included in SARscape Analytics Toolbox - Refinement is applied to refine the results (Figure 4.5).

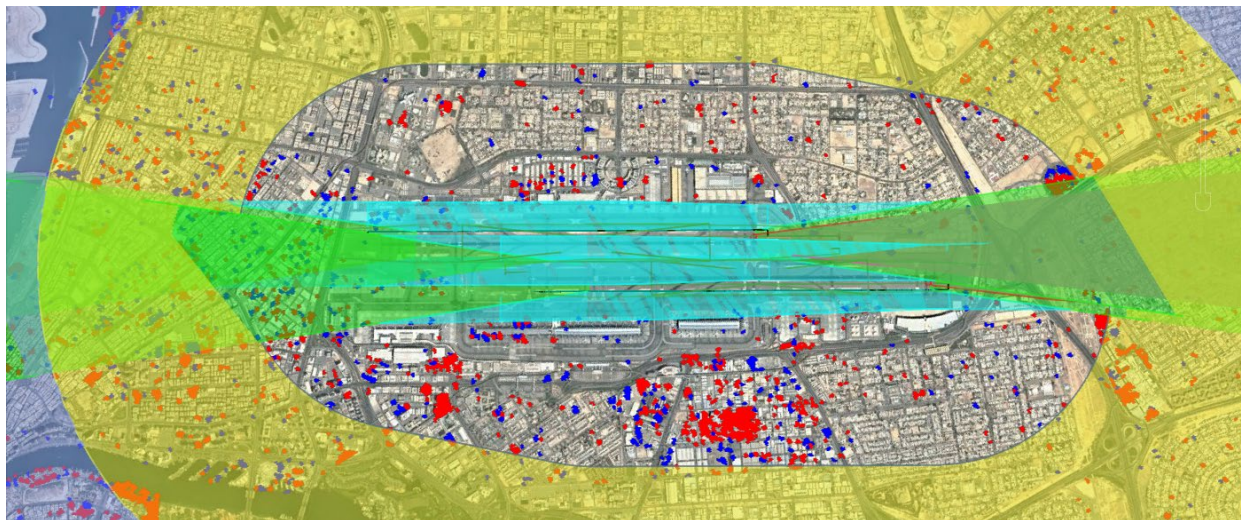


Figure 4.5. Filtered change detection map and OLS protection surfaces around the airport, viewed in Google Earth Pro

Once we have identified the areas where changes have occurred between August 2016 and November 2017, in the second stage, in order to extract the altitude, a pair of scenes collected by TerraSAR-X are required. Due to the high costs associated to new tasking, the use of archive images is an optimal choice. They can be acquired in StripMap (SM) mode - satellite scenes 30 km single polarization, 15 km dual polarization and resolution up to 3 m, or SpotLight (SL) - satellite scenes 10 km x 10 km and resolution up to 2 m .

After an extensive search of archive images, I couldn't identify any pair of scenes with coverage for the area of interest.

Therefore I considered using optical archive satellite images to detect the 3D changes.

#### 4.1.2. 3D change detection using optical satellite imagery

Due to the lack of archive images collected by TerraSAR-X for the area of interest, I considered using optical archive satellite images for detecting 3D changes, collected by the Pléiades-1A.

The used datasets used are as follows (Figure 4.6):

T1 (used as reference): stereoscopic pair collected on 2013-04-14, 0% cloud coverage, 0.5 m spatial resolution at  $20.0^\circ$  incidence angle

T2:

- 2015-08-20, 0% cloud coverage, 0.5 m spatial resolution at  $16.1^\circ$  incidence angle
- 2017-11-29, 0% cloud coverage, 0.5 m spatial resolution at  $18.8^\circ$  angle of incidence
- 2018-05-05, 0% cloud coverage, 0.5 m spatial resolution at  $31.2^\circ$  angle of incidence

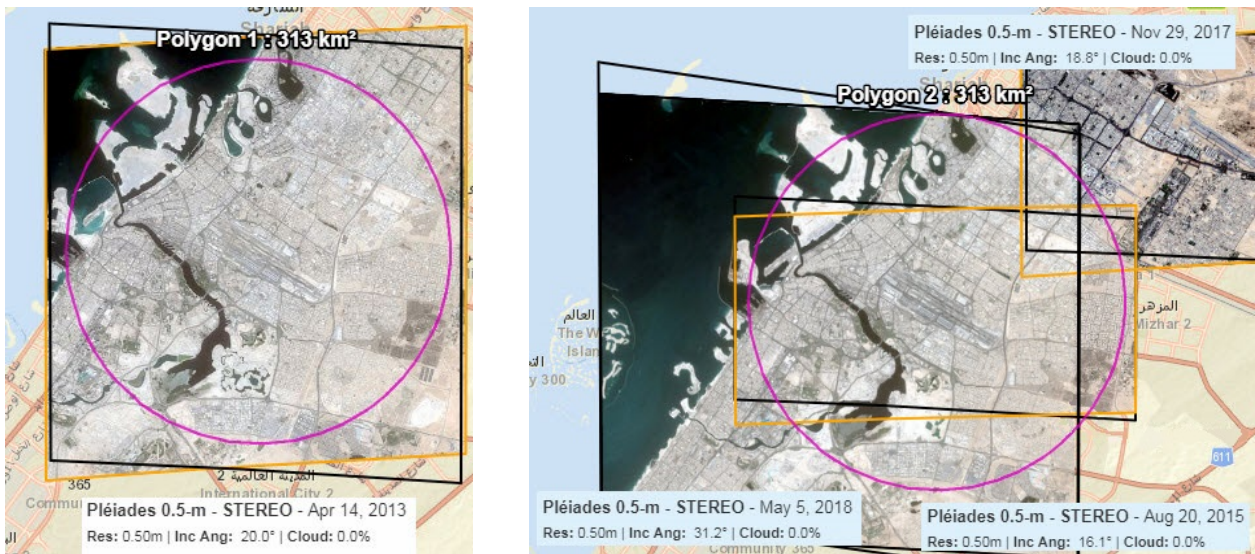


Figure 4.6. Used datasets for the area of interest, T1 on the left, T2 on the right

The images are registered and using GCP and SRTM 3v4 as reference to perform the triangulation, the digital terrain models for the two acquisitions are generated.

The control points (GCP) are determined using GNSS technology, the RTK (Real Time Kinematic) method, real-time kinematic measurements, using the base-rover system. The geolocation accuracy is determined as follows: planimetric accuracy  $\pm 2$  cm and altimetric accuracy  $\pm 3$  cm.

The derived products are the digital surface model (DSM) at 2 m resolution, the digital terrain model (DTM) at 5 m resolution and 50 cm resolution orthomosaic.

Validation of the derived digital models is done by comparison with an independent set of GNSS observations. The results obtained by comparing the digital model with the independent dataset have a vertical accuracy of  $\pm 0.5$  m.

The two DSMs from T1 and T2 acquisitions are compared to extract the spatial information, by calculating the altitude differences  $\Delta Z$  (Figure 4.7).

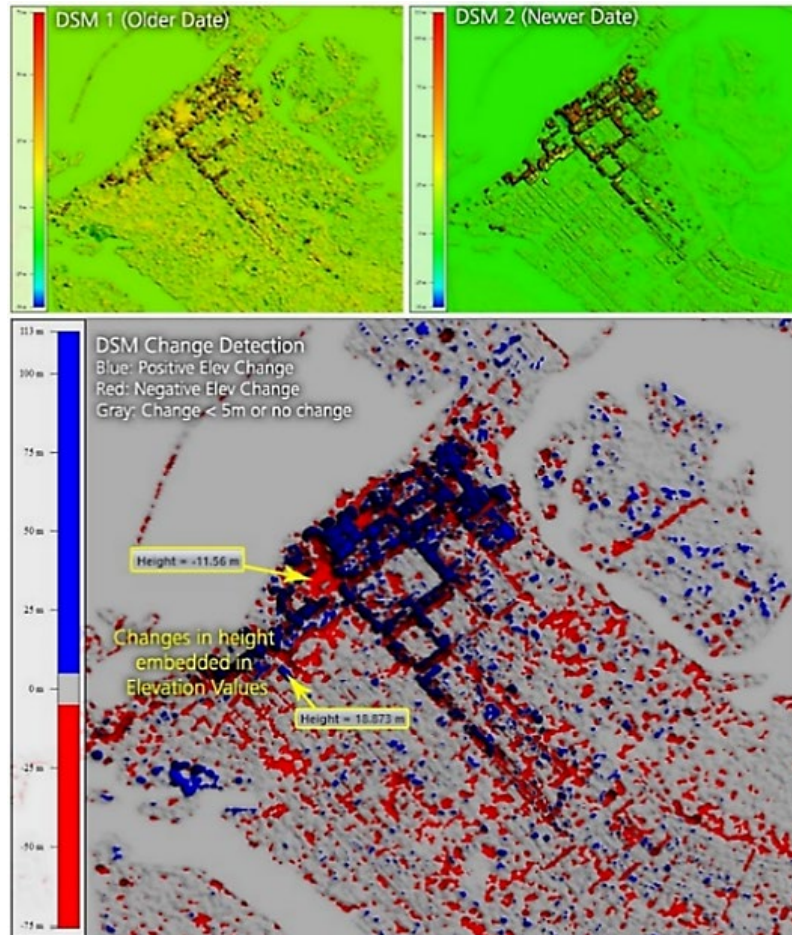


Figure 4.7. Detection of 3D changes resulting from comparing the two DSMs

To interpret Figure 4.7, blue color reflects the positive elevation changes, red color reflects the negative elevation changes, and gray color reflects elevation change less than 5 m or no change.

#### 4.1.3. Conclusions

Due to using digital surface models derived from optical satellite images collected 5 years apart, the algorithms have identified a considerable number of areas where changes have occurred. The results support the concept of 3D change detection in the area of interest, using multitemporal optical satellite images.

At the time of conducting this study, the current generation of Very High Resolution (VHR) SAR sensors is not affordable in terms of associated costs or the medium resolution sensors do not meet the technical requirements of the study, so this method it is too expensive to highlight areas where 3D changes have occurred in the area of interest and streamline the analysis process for the protected airspace around the airport.

## **4.2. Study on processing WorldView-2 satellite imagery and exploiting the derived products, using the SOCET GXP v4.3. Case study of Ras Al Khaimah International Airport, United Arab Emirates**

Located in the Persian Gulf in the United Arab Emirates, 20 km south of Ras al-Khaimah, Ras Al Khaimah International Airport (OMRK) operates on 16/34 runway precision approach CAT I, code 4.

The area of interest has a coverage of approximately 500 km<sup>2</sup> and shows the protection surfaces of the airspace around the airport.

### **4.2.1. Used datasets**

For the area of interest, I used a high-resolution stereoscopic pair; the satellite images were acquired by WorldView-2 optical sensor, on June 21, 2017, with 0% cloud coverage, 0.54 m (GSD) spatial resolution at 23.1° off-nadir angle (measured from nadir to the center of the image at the time of acquisition), 8 multispectral bands, the Sun's elevation at 71.3°.

### **4.2.2. WorldView-2 sensor features and specifications [18]**

The satellite images used for this study are delivered in the Ortho-Ready (2A) Stereo processing level, geometric corrections are applied, this product is mapped to the average base elevation of the terrain covered by each individual satellite scene, to allow orthorectification. They come with Image Support Data files required for processing, and a stereo file that contains information about the images in the stereo pair, the angles at the time of acquisition, elevation and orbit data, geometric calibration, image metadata, radiometric data, and rational functions.

The geolocation accuracy is below 3.5 m CE90 (Circular Error) and 3.6 m LE90 (Linear Error), without the use of ground control points (GCP) and 2 m CE90 with GCP registration. The horizontal accuracy is 2 m CE90 with GCP for 90% confidence level.

### **4.2.3. Processing and exploiting satellite imagery using SOCET GXP v4.3**

**SOCET GXP v4.3** provided by BAE Systems, is a software package for exploiting geospatial data, used in the field of remote sensing, photogrammetry and cartography, for processing satellite images, aerial images collected by UAV platforms or airborne systems and LiDAR data, modeling and 3D visualization, extracting information and video exploitation.

Interoperability with ESRI ArcGIS suite provides the ability to update geospatial databases by integrating extracted features and related metadata.

#### **4.2.3.1. Workspace configuration**

I used the following settings to configure the workspace using SOCET GXP version 4.3:

- Coordinate system: Geographic WGS-84 and vertical datum: MSL EGM96.
- DTED and EGM2008 are provided in SOCET GXP 4.3 package and are associated with the images.

DTED (Digital Terrain Elevation Data) is a standard of digital datasets, delivered in three different levels of detail (Level 0, Level 1 and Level 2), which was developed by the US National Geospatial Intelligence Agency (NGA). DTED0 (Level 0) has a spatial resolution of approximately 900 m (30 seconds of arc), DTED1 (Level 1) has a spatial resolution of approximately 90 m (3 seconds of arc), and DTED2 (Level 2) has a resolution of approximately 30 m (1 second of arc). DTED2 is pre-set by default and is used as a reference for terrain data.

EGM2008 (Earth Gravitational Model 2008), publicly launched by the US National Geospatial Intelligence Agency (NGA), is based on WGS-84 ellipsoid.

#### **4.2.3.2. Input data**

I used 17JUN21065502 and 17JUN21065613 stereo image pair. WorldView-2 panchromatic and multispectral images have complete overlap (100%) for this area of interest.

The archive data received from the provider contains a folder for panchromatic images (056398232010\_01\_P001\_PAN), a folder for multispectral images (056398232010\_01\_P001\_MUL), a folder for GIS files (shapefile type), metadata image files, RPC file and stereo file. Each image is segmented into 3 tiles R1C1, R2C1, R3C1.

I created a virtual image, joining the 3 tiles of each image.

Along with the images, the RPC (Rational Polynomial Coefficient) are imported as the metadata of the geometric model.

#### **4.2.3.3. Image orientation**

In order to achieve image orientation, I considered the RPC (rational polynomial coefficients) method. The RPC equations show the relationship between the image coordinates and the object coordinates for the acquisition sensor.

$$x_{ij} = \frac{P_{i1}(X,Y,Z)_j}{P_{i2}(X,Y,Z)_j} \quad y_{ij} = \frac{P_{i3}(X,Y,Z)_j}{P_{i4}(X,Y,Z)_j} \quad (3)$$

$$P_{n(X,Y,Z)_j} = a_1 + a_2Y + a_3X + a_4Z + a_5YX + a_6YZ + a_7XZ + a_8Y^2 + a_9X^2 + a_{10}Z^2 + \\ + a_{11}XYZ + a_{12}Y^3 + a_{13}YX^2 + a_{14}YZ^2 + a_{15}Y^2X + a_{16}X^3 + a_{17}XZ^2 + \\ + a_{18}Y^2Z + a_{19}X^2Z + a_{20}Z^3 \quad (4)$$

where  $x_{ij}$ ,  $y_{ij}$  are the image coordinates

$X$ ,  $Y$ ,  $Z$  are the coordinates of the points in the object space

$a_i$  are rational polynomial coefficients. [19]

The direct sensor orientation elements are expressed by determining the position of the platform and its elevation elements, or by the RPC equations, which depend on terrain elevation differences.

#### **4.2.3.4. Triangulation**

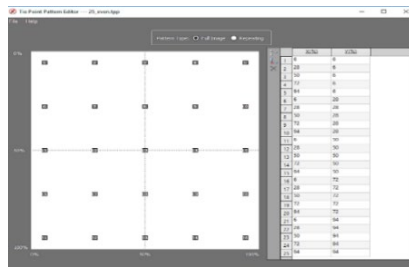
In order to perform the triangulation, as input data I used the two resulting virtual images for the panchromatic bands (Image Setup), then the file containing the coordinates of the GCPs and the DTM used in the triangulation process (DTED2) (Data Setup).

---

The two stereo images are registered, the next step is to mark the control points (GCP) needed for image orientation and the tie points used in the automatic correlation process.

*Automatic Point Measurement* (APM) automatically generates tie points, correlating their positions in all images. APM uses bands and image information to create possible locations of tie points in the double coverage area, then uses image correlation to accurately measure the line and column of pixels for each tie point. Thus, I configured the following settings:

- Algorithm: *APM*
- Strategy: *apm.apm\_strat*
- Point Layout: Tie Point Pattern: *25\_even* (Figure 4.8)



There are several patterns for tie points layout. „Even” patterns cover the entire image and are suitable for satellite images. Selecting a denser pattern is recommended for images that are difficult to correlate.

Figure 4.8. Tie points pattern

The advantages of using the APM algorithm are the verification and elimination of incorrectly chosen tie points (for example in areas covered with vegetation).

The algorithm returned 46 identified image points, whose position is determined by row and column; these can be seen in Figure 4.9. Yellow shows the control points (GCP) and green the tie points.

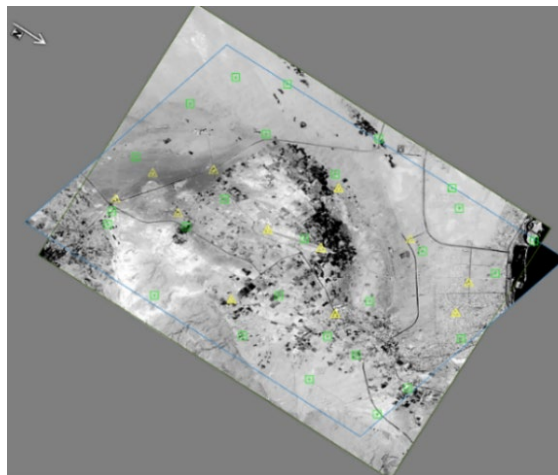


Figure 4.9. Layout of tie points (green) and GCPs (yellow)

In order to solve the triangulation, I configured the following settings:

- Strategy used: *auto\_blunder\_detect.solve* (automatic error detection)
- Using *Interactive Point Measurement/Solve Details*, the control points that enter the triangulation process are selected, and in an IPM Multiport several windows (more than 4 simultaneously) are available to see all the images where the control point is located. In these enlarged windows, image marking is performed using the sketches and GNSS observations.

The control points (GCP) are determined using GNSS technology, RTK (Real Time Kinematic) method, real-time kinematic measurements, using the base-rover system. The geolocation accuracy is determined as follows: planimetric accuracy  $\pm 2$  cm and altimetric accuracy  $\pm 3$  cm.

Tie points and ground control points (GCPs) are used. For each control point the geolocation accuracy and the mean square errors on the directions of the 3 coordinates, are calculated on each direction from the difference between the coordinates of the points measured using GNSS technology and those marked on the images.

The triangulation process is an iterative process. The results are accepted when  $RMS < 1$ , so the process is resumed by remeasuring the control points on the images and eliminating residual errors.

The results obtained in the second iteration are as follows, according to Table 4.1 and Figure 4.10):

*Table 4.1. Accuracy of control points - triangulation of PAN images*

| Description  | $\Delta X$ (m) | $\Delta Y$ (m) | $\Delta Z$ (m) | RMSE (m)     | Eroarea de punctare (pix) |
|--------------|----------------|----------------|----------------|--------------|---------------------------|
| GCP-01A      | 0.141          | 0.276          | -0.106         | 0.328        | 0.22                      |
| GCP-02       | -0.020         | -0.209         | -0.264         | 0.337        | 0.27                      |
| GCP-03       | -0.200         | 0.105          | -0.029         | 0.228        | 0.19                      |
| GCP-04A      | -0.518         | -0.466         | -0.001         | 0.697        | 0.61                      |
| GCP-04B      | -0.508         | -0.192         | -0.297         | 0.619        | 0.33                      |
| GCP-05A      | -0.814         | 0.354          | 0.406          | 0.976        | 0.44                      |
| GCP-05B      | -0.285         | 0.035          | 0.092          | 0.302        | 0.16                      |
| GCP-05C      | -0.254         | -0.250         | 0.250          | 0.435        | 0.25                      |
| GCP-06       | 0.323          | 0.278          | 0.153          | 0.453        | 0.23                      |
| GCP-07A      | -0.056         | 0.236          | -0.388         | 0.458        | 0.29                      |
| GCP-07B      | -0.401         | 0.310          | 0.168          | 0.534        | 0.13                      |
| GCP-07C      | -0.377         | -0.087         | 0.149          | 0.415        | 0.21                      |
| GCP-07D      | -0.033         | -0.121         | 0.119          | 0.173        | 0.28                      |
| GCP-08       | 0.165          | -0.206         | -0.002         | 0.264        | 0.09                      |
| GCP-09       | -0.146         | 0.392          | 0.443          | 0.609        | 0.59                      |
| GCP-09A      | 0.455          | 0.771          | 0.452          | 1.003        | 0.55                      |
| GCP-10B      | -0.262         | 0.219          | -0.175         | 0.384        | 0.46                      |
| GCP-10C      | -0.191         | 0.643          | 0.304          | 0.736        | 0.28                      |
| GCP-11A      | 0.068          | -0.346         | -0.025         | 0.354        | 0.67                      |
| GCP-11B      | 0.151          | -0.218         | 0.054          | 0.271        | 0.27                      |
| GCP-11C      | -0.012         | -0.349         | -0.037         | 0.351        | 0.12                      |
| GCP-12A      | 0.052          | -0.218         | -0.402         | 0.460        | 0.66                      |
| GCP-12B      | 0.131          | -0.178         | 0.002          | 0.221        | 0.27                      |
| GCP-12C      | -0.044         | -0.233         | -0.200         | 0.310        | 0.23                      |
| <b>Total</b> | <b>0.304</b>   | <b>0.323</b>   | <b>0.239</b>   | <b>0.504</b> | <b>0.26</b>               |

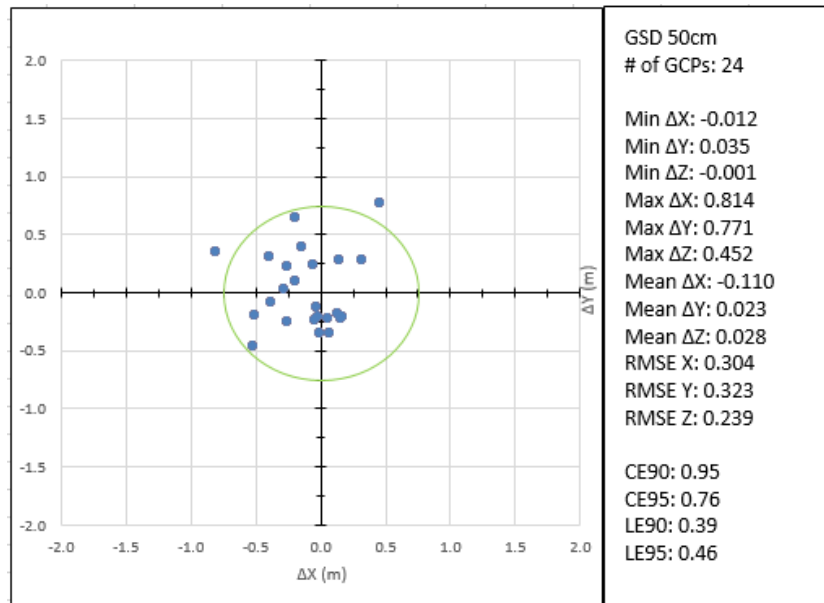


Figure 4.10. Scatter diagram for GCP accuracy, PAN triangulation PAN - CE95

Figure 4.10 shows the scatter plot for the representation of CE95 (Circular Error) of GCP in the triangulation process of panchromatic images, with a confidence level of 95%, CE95 value equals 0.95 m, and the vertical accuracy LE95 equals 0,46 m.

Following the triangulation, the .sup files for each virtual image have been updated with the new parameters.

Similarly, I performed the triangulation of virtual images created for multispectral bands, using .sup files resulting from the triangulation of panchromatic bands.

The following results are obtained for the third iteration (according to Table 4.2 and Figure 4.11):

Table 4.2. Accuracy of control points - triangulation of MSI images

| Description  | $\Delta X$ (m) | $\Delta Y$ (m) | $\Delta Z$ (m) | RMSE (m)     | Eroarea de punctare (pix) |
|--------------|----------------|----------------|----------------|--------------|---------------------------|
| GCP-01A      | -0.503         | -0.100         | 0.052          | 0.515        | 0.05                      |
| GCP-02       | -0.071         | 0.388          | -0.017         | 0.395        | 0.03                      |
| GCP-03       | -0.975         | -1.163         | -1.104         | 1.877        | 0.47                      |
| GCP-04A      | -1.155         | 0.474          | -0.444         | 1.325        | 0.26                      |
| GCP-04B      | -1.555         | 0.100          | -1.085         | 1.899        | 0.27                      |
| GCP-05A      | -1.182         | 0.171          | 0.533          | 1.308        | 0.16                      |
| GCP-05B      | 1.187          | 0.146          | 0.205          | 1.213        | 0.22                      |
| GCP-05C      | 1.557          | -1.508         | 0.988          | 2.382        | 0.32                      |
| GCP-06       | 0.520          | 0.361          | 0.674          | 0.925        | 0.14                      |
| GCP-07A      | -0.290         | 1.392          | -0.202         | 1.436        | 0.14                      |
| GCP-07B      | 0.590          | 1.249          | 1.103          | 1.768        | 0.26                      |
| GCP-07C      | 0.306          | 0.308          | 1.461          | 1.524        | 0.23                      |
| GCP-07D      | -0.470         | 0.009          | -0.092         | 0.479        | 0.14                      |
| GCP-09A      | -0.366         | 0.209          | 0.018          | 0.422        | 0.45                      |
| GCP-10B      | -1.842         | 1.382          | -0.015         | 2.303        | 0.83                      |
| GCP-10C      | -0.019         | -0.690         | 1.843          | 1.968        | 0.33                      |
| GCP-11A      | -0.471         | -0.657         | 0.737          | 1.094        | 0.35                      |
| GCP-11B      | -0.004         | -0.405         | 0.754          | 0.856        | 0.30                      |
| GCP-11C      | -0.529         | -0.669         | 0.697          | 1.101        | 0.11                      |
| GCP-12A      | -0.612         | 0.681          | -0.789         | 1.209        | 0.35                      |
| GCP-12B      | -0.403         | -0.193         | 0.624          | 0.767        | 0.11                      |
| GCP-12C      | -0.528         | -0.230         | -0.244         | 0.625        | 0.30                      |
| <b>Total</b> | <b>0.854</b>   | <b>0.733</b>   | <b>0.793</b>   | <b>1.377</b> | <b>0.22</b>               |

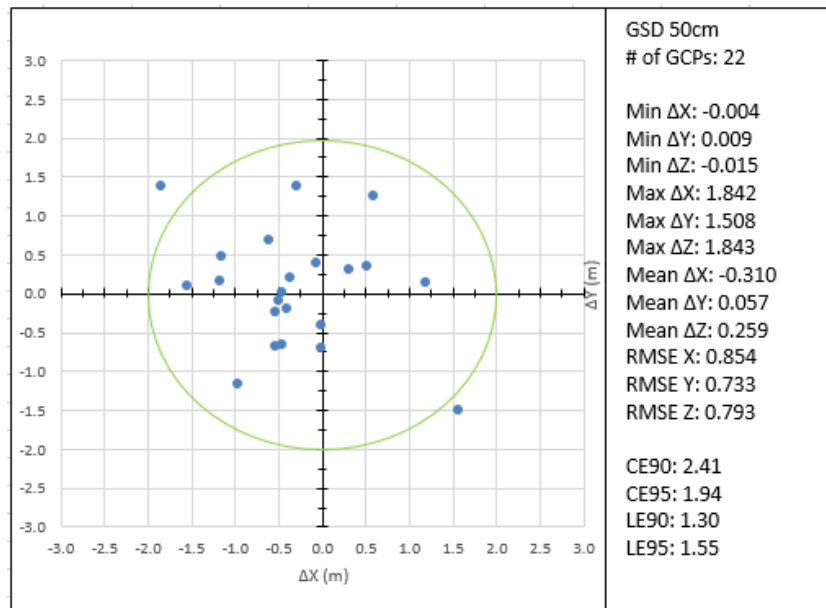


Figure 4.11. Scatter diagram for GCP accuracy, MSI triangulation - CE95

Figure 4.11 shows the scatter plot for the representation of CE95 (Circular Error) of GCP in the triangulation process of multispectral images, with a confidence level of 95%, CE95 value equals 1.94 m and LE95 equals 1.55 m .

Following the process of automatic image triangulation, normalized images are obtained, where the transverse parallax is removed.

In order to check the orthorectified images following the triangulation process, I used the .sup files for the panchromatic and multispectral bands, and the correlated images are viewed in two panels; the same point will be in the center of the image in both panels, simultaneously (Figure 4.12).

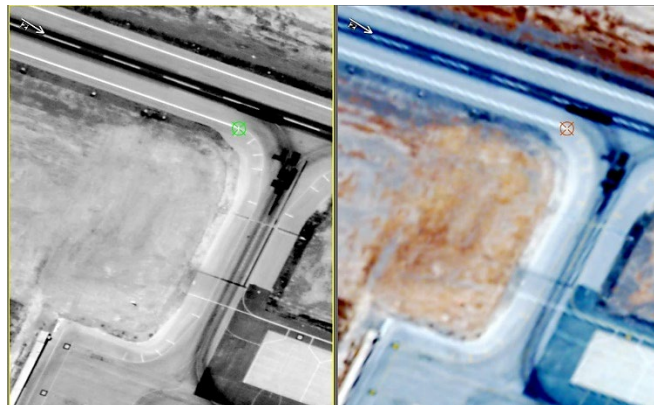


Figure 4.12. Checking orthorectified images

#### 4.2.3.5. Generating the digital surface model

Following the automatic triangulation, the digital surface model can be generated.

The generation of the digital surface model is done with *Automatic Terrain Generation*. The .sup files resulting from the triangulation process are used.

I configured the following settings in the Automatic Terrain Generation window:

- DTM Setup: Grid (this format makes editing easier compared to the TIN format)
  - Format: Socet GXP Grid
  - DTM boundary (.shp created to include the obstacle limitation surfaces and terrain and obstacle data collection areas for Ras Al Khaimah Airport)
    - Spatial resolution: X spacing 0.5 m  
Y spacing 0.5 m
  - The number of grid points is automatically calculated, depending on the user-defined area
  - Unit of measurement: meters
  - I used the *ASM (Automatic Spatial Modeler)* algorithm, with the following parameters:
    - Strategy: *asm\_urban.strategy* (used for urban areas with tall buildings)
    - DTM Filters indicate the type of digital model created by the algorithm: DEM (Bare Earth), DSM and DSM filtering by removing small objects that have a minimum height of 1 m and a maximum width of 10 m and large objects that have a minimum height of 1.5 m and a maximum width of 100 m.
    - Editing Signature Removal: vertical deviation: 0.25 m
    - Eliminate wells: minimum depth: 3 m
    - Smoothing: Low
    - High precision and low processing speed (Precision/Speed: High/Slow)
  - Maximum number of image pairs: 1
  - Number of processes: 2

The ASM algorithm uses a GPU (Graphics Processing Unit) and a multi-threaded CPU (Central Processing Unit), which does not require 4 or more processors. When working with a single workstation, the number of processes is defined as 1 or 2. For high-performance workstations, a number of 4 processes is preferred.

The ASM algorithm processed on a workstation with Intel Xeon CPU, 3.2 GHz (four processors), 12 GB RAM and NVIDIA GeForce GTX 750Ti GPU.

- Seed DTM is a file that contains elevation data for DTM generation. Using the AutoDTED button to select the most appropriate terrain file.

The resulting digital surface model and the corresponding panchromatic image are used to edit the model in the Stereo environment, obtaining pronounced terrain features.

#### **4.2.3.6. Filtering the digital surface model**

There is no automatic extraction method to return a correct and complete result by removing structures, vegetation and other elements from the earth's surface. Thus, in order to obtain a digital terrain model, it is necessary to edit the 3D model.

Adding planimetric details and 3D breaklines in a stereo viewing environment in order to represent the terrain more accurately can be an intense process, depending on the area of interest. For this case study, the relief is predominantly smooth in the desert area.

Errors resulting from the automatic image correlation process lead to obtaining model artifacts. These are eliminated by correcting erroneous Z elevation values.

Filtering and interpolation give an estimated value, taking into account the elevations of the neighboring points and the distances between them.

#### **4.2.3.7. Generating the digital terrain model**

Following the digital surface model filtering process, DTM is obtained (Figure 4.13). Due to the elimination of some points in the filtering process, in order to obtain a regular network of points, the digital terrain model must be interpolated.

The quality of the DTM is determined by the methods of modeling and interpolation of the earth's surface.

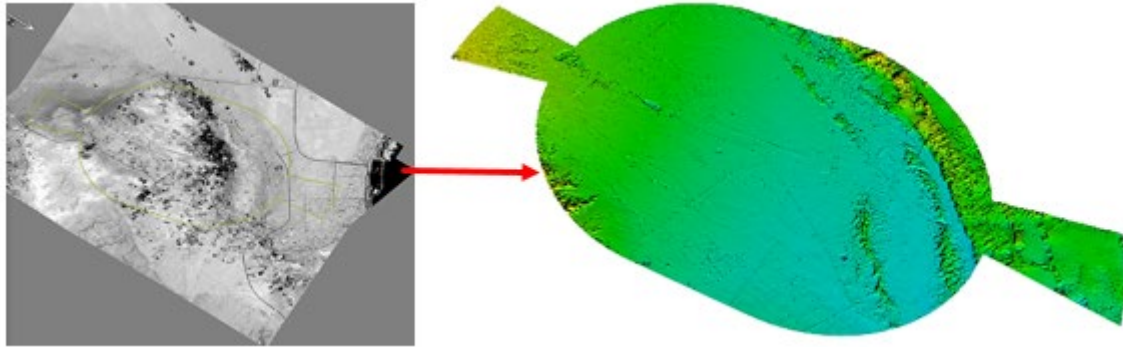


Figure 4.13. Digital terrain model for the protected airspace around the airport

#### **4.2.3.8. Generating the orthomosaic**

True Orthophoto is the orthorectified image, with applied geometric corrections to eliminate distortions of the buildings perspective.

The resulting product after applying mosaic lines and spatial filtering procedures (Feathering, Smoothing) and radiometric corrections, is the orthophotoplan, at 50 cm spatial resolution (GSD).

#### **4.2.3.9. Validation of derived digital terrain models**

Evaluating the accuracy of a digital model is done by comparing it with an independent set of GNSS observations. This dataset contains known elevation points along the runway centerline, the runway thresholds, the holding positions and the parking positions on the apron.

The results obtained by comparing the digital model with 124 points determined using GNSS technology, showed a vertical accuracy of  $\pm 0.53$  m.

The accuracy of the DTM depends on the accuracy of the RPC model and the use of tie points and control points in the orthorectification process, so that it can be edited using breaklines.

The spatial resolution of the grid is specified, but it is limited by the resolution of the raw images. This also applies to contours: if the equidistance of the contours is increased, the accuracy doesn't change, as they are generated based on the DTM.

#### **4.2.3.10. Extracting geospatial information**

3D information is extracted from the derived products in order to integrate it into a geospatial database, using the ESRI ArcGIS suite. Feature extraction can be done automatically (*Automatic Feature Extraction*) or manually.

SOCET GXP allows the classification by layers and into feature classes (for example Runway, Buildings, etc.), thus facilitating populating the database and updating the attributes of each feature.

Feature classes are collected in stereo mode, using orthorectified images.

In order to configure the database specifications, lists of codes and defined values for class elements are used (Figure 4.14). Symbols, colors, annotations for visualization can also be configured in GIS environment.

*Spatially Enabled Exploitation (SEE)* allows self-assignment and populating the database in ESRI Geodatabase format, via an XML file.

SOCET for ArcGIS extension allows the use of SOCET GXP and ESRI ArcGIS simultaneously, connecting the database with real-time updates.

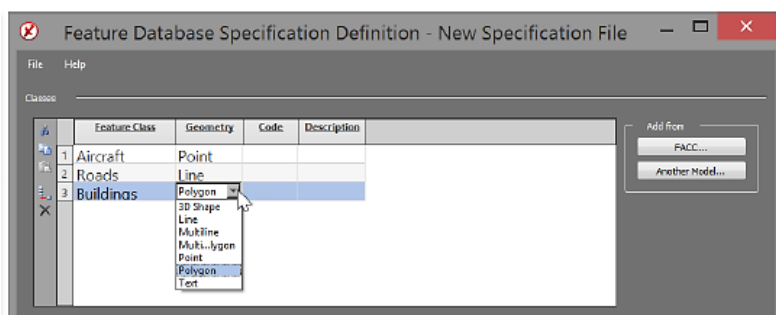


Figure 4.14. Feature classes, geometry, code, type and their attributes

#### 4.2.3.11. Buildings 3D modeling

Complex buildings and structures are extracted according to the LOD (Level of Detail) specific to each project.

LOD - Level of Detail is a concept of OCG CityGML 2.0 standard [20] whose purpose is to differentiate the multi-scale representations of 3D models of a city and to indicate the geometric details of a 3D model, primarily of buildings.

LOD 1 model comprises prismatic buildings with flat roofs and is known as the "block model".

In this case, I performed the 3D modeling of the buildings for LOD 1.3 level of detail (Figure 4.15). Information extraction and 3D modeling is performed in stereo mode. The 3D model is obtained by extruding the footprint of the building at a uniform height.

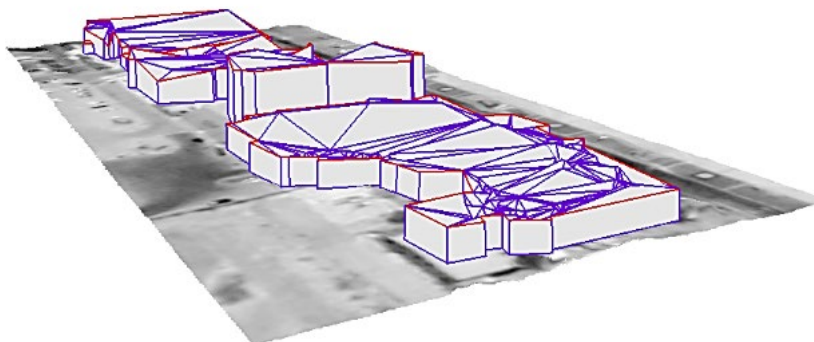


Figure 4.15. Building modeling for the level of detail LOD 1.3

#### 4.2.3.12. The quality of the derived digital terrain models

Considering the same dataset of GNSS observations used to validate the derived digital models by exploiting remote sensing images using SOCET GXP v4.3 software, I performed the quality analysis of the two products (Table 4.3):

Table 4.3. The quality of digital models - extracted from the data set

| Obs Id | Description       | Easting UTM40N | Northing UTM40N | Z (GNSS) | Z (DTM) | $\Delta Z$ (m) | RMSE  |
|--------|-------------------|----------------|-----------------|----------|---------|----------------|-------|
| 1431   | THR               | 392972.258     | 2835112.477     | 19.533   | 19.349  | 0.184          | 0.535 |
| 1432   | THR               | 393931.366     | 2831477.688     | 28.689   | 28.181  | 0.508          |       |
| 1433   | ARP               | 393451.812     | 2833295.082     | 23.289   | 22.779  | 0.510          |       |
| 1450   | Runway_Profile_Pt | 392958.870     | 2835162.500     | 19.310   | 19.225  | 0.085          |       |
| 1451   | Runway_Profile_Pt | 392959.950     | 2835158.080     | 19.410   | 19.538  | -0.128         |       |

Table 4.3 is extracted from the dataset, so the check points indicate the accuracy of the models, in the above table the RMSE value 0.53 m is calculated for the entire dataset.

The results obtained by comparing the digital model with 124 points determined using GNSS technology, have a vertical accuracy of  $\pm 0.53$  m.

#### 4.2.4. Conclusions

The semi-automatic processing of stereo satellite images acquired by WorldView-2 optical sensor is described using SOCET GXP v4.3 software, ground control points (GCP) determined using GNSS observations, in order to generate quality assured 3D models and high-resolution orthomosaic.

Satellite remote sensing is an efficient method of acquiring geospatial data over the entire area of protected airspace around the airport, in terms of:

- capital costs (for example, a new acquisition of optical stereo images collected by WorldView-2 optical sensor for the area of interest, and processing in order to derive digital models and the orthomosaic would amount \$17,750, without any costs associated to surveying GCP);
- the duration of the acquisition related to the area of interest (the collection window depends on the cloud coverage of the area of interest);
- the efficiency of the measurement;
- the accuracy of the determinations, which fall within the tolerances imposed by ICAO and EUROCONTROL for aeronautical studies;
- the degree of automation;
- the effort to validate the models and the orthomosaic, considering additional GNSS determinations are needed;
- the degree of reusing the data;
- the risk of omitting obstacles.

Some small diameter objects/structures (antennas, poles, etc.) could not be identified, therefore GNSS or classical determinations are required.

The derived products are used to extract geospatial information and create aeronautical datasets: Aerodrome Mapping Database (AMDB), terrain and obstacle datasets (eTOD), described in Chapter 5.

## Chapter 5. Aeronautical information systems

### 5.1. Types of database entities

#### 5.1.1. Obstacle limitation surfaces

Obstacle Limitation Surfaces (OLS) are the protection surfaces that set the height limits of structures around an aerodrome. Objects that infringe these surfaces are considered obstacles.

Obstacle limitation surfaces are described as follows, according to RACR-AD-PETA [21] and ICAO Annex 14 to the Chicago Convention [22], Volume I, Chapter 4 (Figure 5.1):

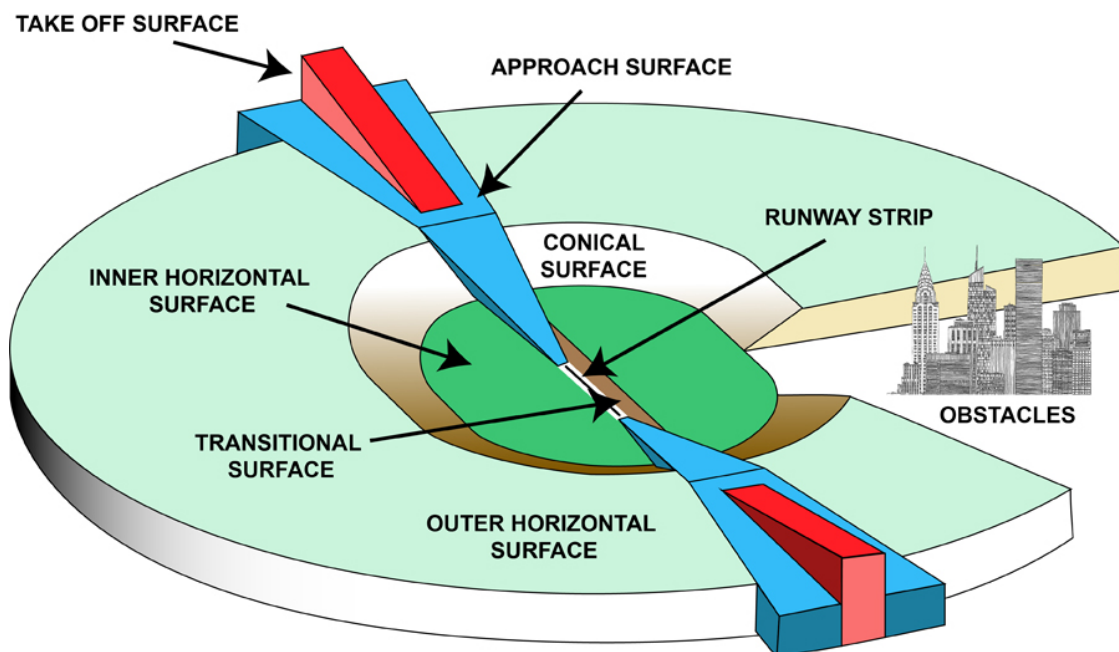


Figure 5.1. Obstacle limitation surfaces

**„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 .” [21], [22]

**„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.”[21], [22]

**„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.”[21], [22]

**"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." [21], [22]

**„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." [21], [22]

**„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. " [21], [22]

**„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 horizontal surface. The slope of the inner transition surface must be measured in a vertical plane perpendicular to the runway centerline." [21], [22]

**„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." [21], [22]

**„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. " [23]

The specifications of obstacle limitation surfaces are described as follows, according to RACR-AD-PETA [21] and ICAO Annex 14 to the Chicago Convention [22], Volume 1, Chapter 4 (Table 5.1, Table 5.2):

Table 5.1 Dimensions and slopes of obstacle limitation surfaces; Take-off Runways [21,22]

| 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%      |

Table 5.2. Dimensions and slopes of obstacle limitation surfaces; Approach Runways [22]

| 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    |
| <b>CONICAL SURFACE</b>            |                         |        |        |        |                        |         |         |                             |            |         |
| 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   |
| <b>INNER HORIZONTAL SURFACE</b>   |                         |        |        |        |                        |         |         |                             |            |         |
| 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  |
| <b>INNER APPROACH SURFACE</b>     |                         |        |        |        |                        |         |         |                             |            |         |
| 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%      |
| <b>APPROACH SURFACE</b>           |                         |        |        |        |                        |         |         |                             |            |         |
| 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%     |
| <b>The first section</b>          |                         |        |        |        |                        |         |         |                             |            |         |
| 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%      |
| <b>Second section</b>             |                         |        |        |        |                        |         |         |                             |            |         |
| Length                            | -                       | -      | -      | -      | -                      | 3600 m  | 3600 m  | 12000 m                     | 3600 m     | 3600 m  |
| Slope                             | -                       | -      | -      | -      | -                      | 2.5%    | 2.5%    | 3%                          | 2.5%       | 2.5%    |
| <b>Horizontal section</b>         |                         |        |        |        |                        |         |         |                             |            |         |
| Length                            | -                       | -      | -      | -      | -                      | 8400 m  | 8400 m  | -                           | 8400 m     | 8400 m  |
| Total length                      | -                       | -      | -      | -      | -                      | 15000 m | 15000 m | 15000 m                     | 15000 m    | 15000 m |
| <b>TRANSITIONAL SURFACE</b>       |                         |        |        |        |                        |         |         |                             |            |         |
| Slope                             | 20%                     | 20%    | 14.3%  | 14.3%  | 20%                    | 14.3%   | 14.3%   | 14.3%                       | 14.3%      | 14.3%   |
| <b>INNER TRANSITIONAL SURFACE</b> |                         |        |        |        |                        |         |         |                             |            |         |
| Slope                             | -                       | -      | -      | -      | -                      | -       | -       | 40%                         | 33.3%      | 33.3%   |
| <b>BALKED LANDING SURFACE</b>     |                         |        |        |        |                        |         |         |                             |            |         |
| 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%   |

### 5.1.2. Electronic Terrain and Obstacle Data

#### 5.1.2.1. Terrain and Obstacle Data collection surfaces

Coverage areas for electronic terrain and obstacle data sets shall be specified as follows, in accordance with ICAO Annex 15 to the Chicago Convention.[24], RACR-AIS [25], Chapter 10, Eurocontrol TOD Manual [26], ICAO Doc 10066 PANS-AIM [27] and ICAO Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information [28]:

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

Area 2: within the vicinity of the aerodrome, subdivided as follows (Figure 5.2):

- 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 5.3).

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 approach runway, Category II or III (Figure 5.3).

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. ” [24], [25]

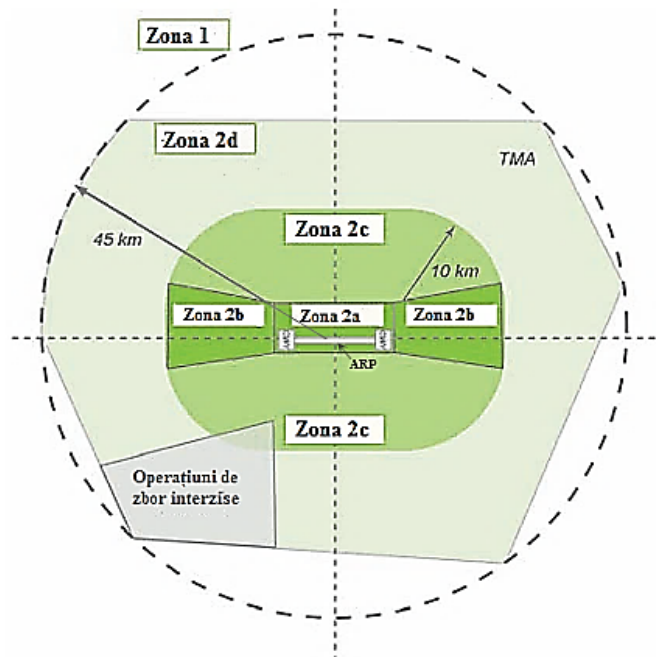


Figure 5.2. Field and obstacle data collection areas, Zone 1 and Zone 2 [29]

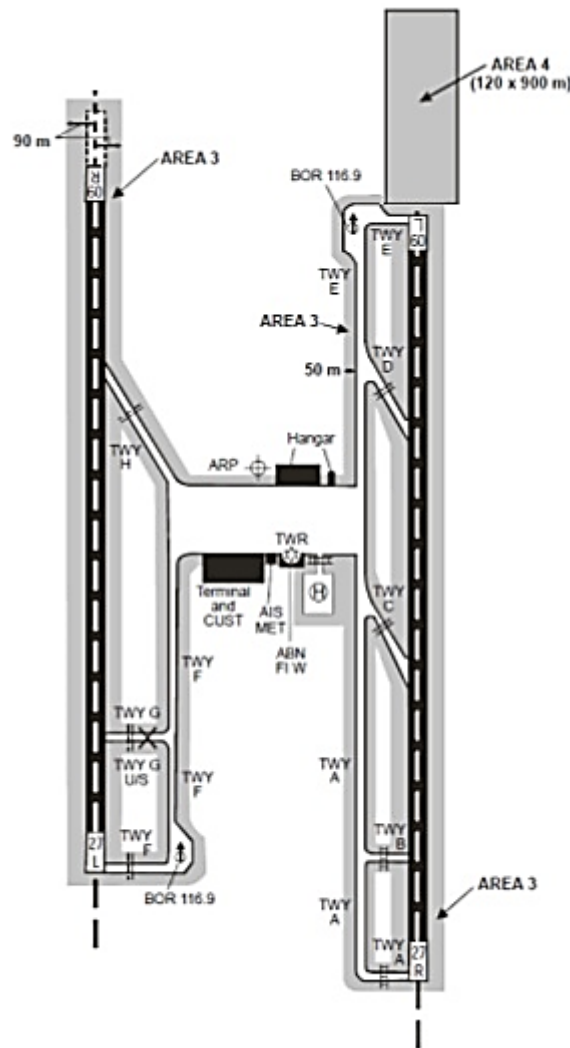


Figure 5.3. Field and obstacle data collection areas, Zone 3 and Zone 4 [29]

### 5.1.2.2 Electronic Terrain and Obstacle Data

Electronic terrain and obstacle data must meet the requirements according to ICAO Annex 15 to the Chicago Convention [24], RACR-AIS [25], Chapter 10, Eurocontrol TOD Manual [26], ICAO Doc 10066 PANS-AIM [27] and ICAO Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information [28].

#### 5.1.2.2.1. 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."* [24], [25]

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. " [24], [25]*

#### **5.1.2.2.2. 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, located in the area intended for the movement of aircraft on the movement surface, or those extending over a defined area intended to protect aircraft during flight, through 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 " [24], [25]*

#### **5.2. Levels of abstraction**

The first step in designing databases is conceptualization, using the methodology, the descriptive standards and formats for spatial data exchange. Spatial data modeling influences the analysis process, therefore a key element in the design of databases is the data model.

The architecture of a database system must facilitate the user's interaction with the interface, by separating the data structure from the operable elements. Data abstraction is used on three levels of representation and perception, described below.

### 5.2.1. The conceptual model

The conceptual model represents an organized visualization of the the database concepts and their relations and has the role of describing the system through entities, their attributes and the constraints between them, thus defining the content of the database (Figure 5.4).

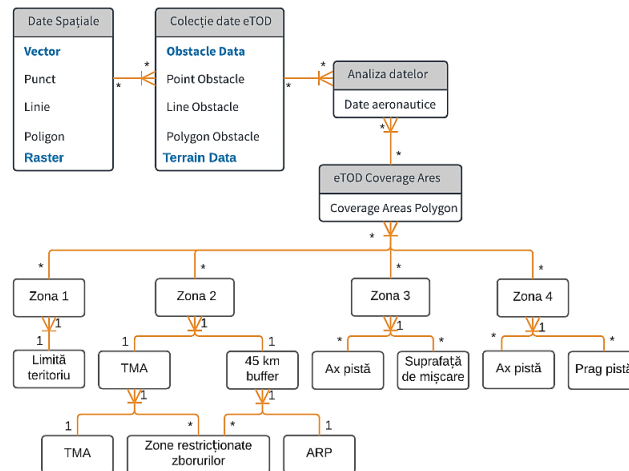


Figure 5.4. eTOD conceptual model [30]

### 5.2.2. The logical model

The logical model specifies the structure of the database, through data collections and the relations between them, in a form that can be used for design (Figure 5.5).

The UML (Unified Modeling Language) is a visual modeling tool, which translates conceptual entities into the structure of the database. I performed UML modeling using Enterprise Architect v14 software, Sparx Systems.



- information about the time limit of representation: creation date, date of issue
- data source information
- maintenance information
- quality information
- information about spatial representation
- information about the reference system
- distribution information
- citation information

Table 5.3. Terrain data numerical requirements [24]

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

Table 5.4. Obstacle data numerical requirements [24]

|                                     | <b>Area 1</b> | <b>Area 2</b> | <b>Area 3</b> | <b>Area 4</b> |
|-------------------------------------|---------------|---------------|---------------|---------------|
| <b>Vertical accuracy</b>            | 30 m          | 3 m           | 0.5 m         | 1 m           |
| <b>Vertical resolution</b>          | 1 m           | 0.1 m         | 0.01 m        | 0.1 m         |
| <b>Horizontal accuracy</b>          | 50 m          | 5 m           | 0.5 m         | 2.5 m         |
| <b>Confidence level</b>             | 90%           | 90%           | 90%           | 90%           |
| <b>Integrity<br/>classification</b> | routine       | essential     | essential     | essential     |
| <b>Maintenance period</b>           | as required   | as required   | as required   | as required   |

Cardinality is the constraint at the occurrence level of an element of the metadata model, which defines the mandatory and optional metadata (Table 5.5, Table 5.6).

Table 5.5 Terrain attributes [24]

| <b>Terrain attribute</b>           | <b>Mandatory / Optional</b> |
|------------------------------------|-----------------------------|
| <b>Area of coverage</b>            | Mandatory                   |
| <b>Data originator identifier</b>  | Mandatory                   |
| <b>Data source identifier</b>      | Mandatory                   |
| <b>Acquisition method</b>          | Mandatory                   |
| <b>Post spacing</b>                | Mandatory                   |
| <b>Horizontal reference system</b> | Mandatory                   |
| <b>Horizontal resolution</b>       | Mandatory                   |
| <b>Horizontal accuracy</b>         | Mandatory                   |
| <b>Horizontal confidence level</b> | Mandatory                   |
| <b>Horizontal position</b>         | Mandatory                   |
| <b>Elevation</b>                   | Mandatory                   |
| <b>Elevation reference</b>         | Mandatory                   |
| <b>Vertical reference system</b>   | Mandatory                   |
| <b>Vertical resolution</b>         | Mandatory                   |

| <i>Terrain attribute</i>         | <i>Mandatory / Optional</i> |
|----------------------------------|-----------------------------|
| <b>Vertical accuracy</b>         | <i>Mandatory</i>            |
| <b>Vertical confidence level</b> | <i>Mandatory</i>            |
| <b>Surface type</b>              | <i>Optional</i>             |
| <b>Recorded surface</b>          | <i>Mandatory</i>            |
| <b>Penetration level</b>         | <i>Optional</i>             |
| <b>Known variations</b>          | <i>Optional</i>             |
| <b>Integrity</b>                 | <i>Mandatory</i>            |
| <b>Date and time stamp</b>       | <i>Mandatory</i>            |
| <b>Unit of measurement used</b>  | <i>Mandatory</i>            |

Table 5.6. Obstacle attributes [24]

| <i>Obstacle attribute</i>          | <i>Mandatory / Optional</i> |
|------------------------------------|-----------------------------|
| <b>Area of coverage</b>            | <i>Mandatory</i>            |
| <b>Data originator identifier</b>  | <i>Mandatory</i>            |
| <b>Data source identifier</b>      | <i>Mandatory</i>            |
| <b>Obstacle identifier</b>         | <i>Mandatory</i>            |
| <b>Horizontal accuracy</b>         | <i>Mandatory</i>            |
| <b>Horizontal confidence level</b> | <i>Mandatory</i>            |
| <b>Horizontal position</b>         | <i>Mandatory</i>            |
| <b>Horizontal resolution</b>       | <i>Mandatory</i>            |
| <b>Horizontal extent</b>           | <i>Mandatory</i>            |
| <b>Horizontal reference system</b> | <i>Mandatory</i>            |
| <b>Elevation</b>                   | <i>Mandatory</i>            |
| <b>Height</b>                      | <i>Optional</i>             |
| <b>Vertical accuracy</b>           | <i>Mandatory</i>            |
| <b>Vertical confidence level</b>   | <i>Mandatory</i>            |
| <b>Vertical resolution</b>         | <i>Mandatory</i>            |
| <b>Vertical reference system</b>   | <i>Mandatory</i>            |
| <b>Obstacle type</b>               | <i>Mandatory</i>            |
| <b>Geometry type</b>               | <i>Mandatory</i>            |
| <b>Integrity</b>                   | <i>Mandatory</i>            |
| <b>Date and time stamp</b>         | <i>Mandatory</i>            |
| <b>Unit of measurement used</b>    | <i>Mandatory</i>            |
| <b>Operations</b>                  | <i>Optional</i>             |
| <b>Effectivity</b>                 | <i>Optional</i>             |
| <b>Lighting</b>                    | <i>Mandatory</i>            |
| <b>Marking</b>                     | <i>Mandatory</i>            |

#### 5.4. Data exchange

The aeronautical data exchange is performed using the AIXM model (The Aeronautical Information Exchange Model), which is the standardized XML encoding used to describe, store and exchange the aeronautical information (Figures 5.7 and 5.8).

AIXM is the global aeronautical data standard, used to exchange aeronautical information between data providers and AIS (Aeronautical Information Service) and between AISP (Aeronautical Information Service Provider) and national or international databases, as well as subsequent users. .

The purpose of using the AIXM model is to ensure interoperability by distributing quality aeronautical information, while maintaining data integrity and consistency. These aspects are specified in the Aeronautical Data Quality Requirements (ADQ).

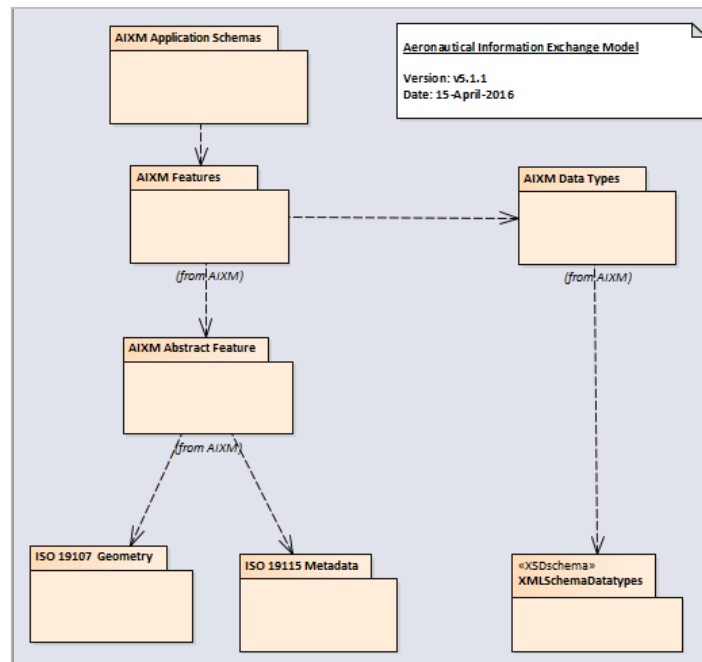


Figure 5.7. Package Diagram AIXM v5.1.1, using UML language, viewed with Enterprise Architect

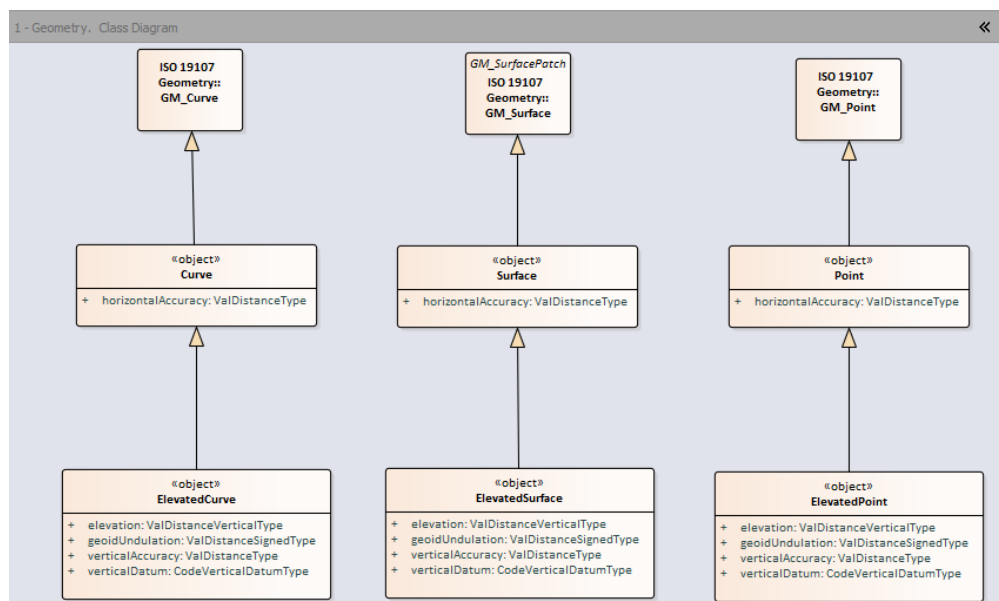


Figure 5.8. Class diagram in AIXM v5.1.1, using UML language, viewed with Enterprise Architect

AIXM was developed by the FAA (Federal Aviation Administration), NGA (National Geospatial Intelligence Agency) and EUROCONTROL (European Organization for the Safety of Air Navigation).

The Terrain Information Exchange Model (TIXM) is similar to AIXM. TIXM is being developed by EUROCONTROL (European Organization for the Safety of Air Navigation).

## 5.5. Aerodrome Mapping Database (AMDB)

Aerodrome Mapping Database (AMDB) is a collection of spatial datasets and their attributes, which provide information about the general plan of the aerodrome. These geospatial datasets describe the aerodrome elements, terrain data, obstacle data, and

air navigation data. AMDB is the support for any operation on the movement surface of the aerodrome, aeronautical charts production, the design of airport infrastructure and efficient management of aeronautical data.

The standards for designing, implementing, populating with attributes, maintaining and distributing an aerodrome mapping database are:

- EUROCAE ED-99D[31], EUROCAE ED-119C [32],
- ICAO Annexes 14 and 15 and
- ISO 19100 standardization framework.

SWIM (System Wide Information Management) is a collaborative, standardized, and managed way for applications to interact in a networked environment.

SWIM considerations in relation to AMDB requirements concern:

- Automation in order to improve the quality, efficiency and cost-effectiveness of aeronautical information services.
- The interoperability of the aeronautical information exchange is achieved through standardized information services, which ensure the compatibility and consistency of data formats.
- Data exchange using the UML model, AMXM (Aerodrome Mapping Exchange Model) to facilitate interoperability.

#### **5.5.1. AMDB applications**

- Complex master plan of the aerodrome
- Airport infrastructure design
- System Wide Information Management (SWIM)
- Airport and airline resource management
- Production and maintenance of digital aeronautical charts
- Facilities management by:
  - Increased efficiency of operations
  - Traffic awareness
  - Vehicle navigation system (accurate location of taxiway lighting)
  - A-SMGCS (Advanced Surface Movement Guidance and Control System) - that prevents runway incursions
  - ERDS (Emergency Response Driving Simulator) - Simulator for emergency response
- Emergency response
- Security management
- RDMS (Runway Debris Management System) - Foreign Object Debris Management and Identification System (FOD)
- Flight simulator and training
- Synthetic image system

### 5.5.2. AMDB structure - Types of AMDB entities

To ensure the consistency and quality of aerodrome spatial data, aerodrome mapping data is supported by electronic terrain and obstacle data (eTOD) for Zone 3.

The AMDB feature classes are shown in Figures 5.9 and 5.10.

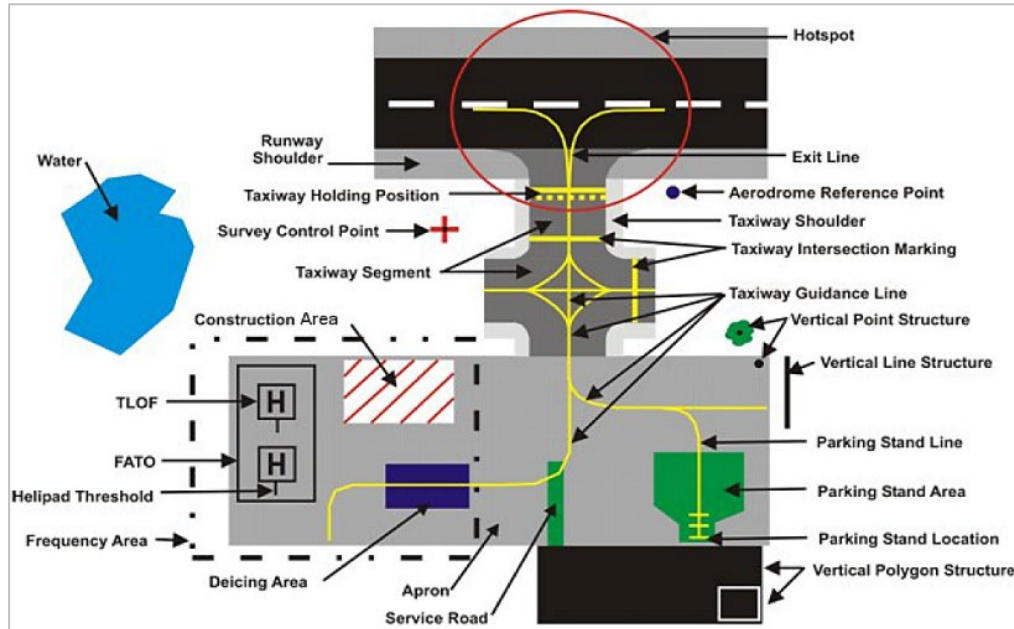


Figure 5.9. AMDB feature classes [31]

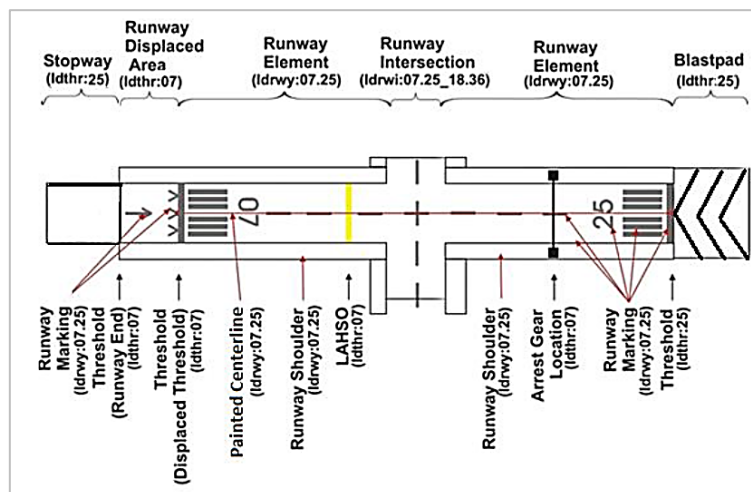


Figure 5.10. Graphical representation of the Runway feature classes [31]

**Aerodrome Reference Point** - ARP, the designated geographical location of an aerodrome, published in the AIP.

**Aerodrome Sign** - A sign presenting messages related to aircraft and vehicles movement.

**Aerodrome Surface Lighting** - Lighting on the movement surface of the aerodrome.

**Apron Element** - The parts of a defined apron area that are not covered by Parking Stand Area features or Taxiway Element features.

**Arresting Gear Location** - Location of the arresting gear cable across the runway.

**Arresting System Location** - The location of the arresting system containing high energy absorbing material, located at the end of a runway or stopway, designed to crush under the weight of an aircraft, as the material exerts deceleration forces on the aircraft landing gear.

**ASRN Edge - Aerodrome Surface Routing Network Edge:** A directional or bidirectional connection between two ASRN nodes features with adjacent geometry, which can be used for graphical depiction of the taxi route (Figure 5.11).

**ASRN Node - Aerodrome Surface Routing Network Node:** Representation of the intersection of two or more aerodrome features related to taxi operations or other special locations, such as the holding position or entry or exit to a parking area (Figure 5.11).

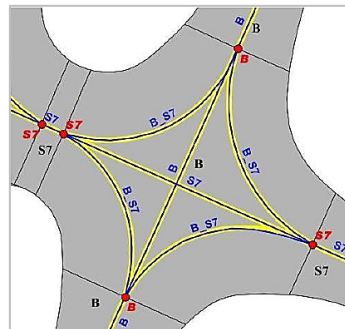


Figure 5.11. Graphical depiction of ASRN Node (red) and ASRN Edge (blue) features [31]

**ATC Blind Spot** - A location on an aerodrome movement area that is not visible to ATC personnel due to obstructions and is not designated as a Hotspot.

**Blastpad** - Areas in extension of runways or stopways usually covered by chevrons, to identify unusable areas for landing, take-off and taxiing, which are intended to reduce the erosive effect of the high wind forces produced by airplanes at the beginning of their take-off roll.

**Bridge Side** - Line representing the side extent of aerodrome features associated with the vertical drop section of an overpass.

**Construction Area** – Part of an aerodrome area under construction.

**Deicing Area** - An area comprising an inner area for parking an aircraft to receive deicing treatment and an outer area for the maneuvering of two or more mobile deicing equipment.

**Deicing Group** - A group of deicing areas.

**Final Approach And Take Off Area- FATO.** A defined area over which the final phase of the approach maneuver to hover or landing is complete or from which the take-off maneuver is commenced.

**Frequency Area** - Designated part of an aerodrome surface where a specific frequency is required by air traffic control or ground control.

**Helipad Threshold** - Threshold of a helipad.

**Hotspot** - A location on an aerodrome movement area with a history or potential risk of collision or runway incursion and where increased attention from pilots/drivers is required.

*Land And Hold Short Operation Location- LAHSO.* Location of marking used for Land and Hold Short Operations (LAHSO).

*Painted Centerline* – Virtual line intended to give a continuous line along the runway centreline, precluding extension through RunwayDisplacedAreas, which connects the two thresholds in case of a bidirectional runway, or the threshold and the opposite end of the runway in case of a unidirectional runway.

*Parking Stand Area* – A designated area on an apron intended to be used for parking an aircraft.

*Parking Stand Location* - The location of an aircraft stand.

*Position Marking* - Location on the movement area surface used for air traffic control clearances, which could be a painted marking or a sign.

*Runway Centerline Point* - A point located on the runway centerline.

*Runway Displaced Area* - That portion of the runway between the beginning of the runway and the displaced threshold.

*Runway Element* - A runway element may consist of one or more polygons that are not defined as other portions of the runway feature.

*Runway Exit Line* – Guidance line painted on the runway exit leading from the runway to a taxiway.

*Runway Intersection* - The intersecting area shared by two or more runways.

*Runway Marking-* These markings may include runway designation marking, runway centerline markings, threshold markings, traverse stripes, touchdown zone markings and runway side stripe markings.

*Runway Shoulder* - The area adjacent to the edge of a runway pavement so prepared as to provide a transition between the runway and the adjacent surface.

*Runway Threshold* - The beginning of that portion of the runway that is available for landing or the beginning of the runway area suitable for non-landing operations.

*Service Road* - may consist of one or more polygons. Service roads can exist both inside and outside the aerodrome's movement area.

*Stand Guidance Line* – Guidance line on a designated area on an apron the intended to be used for parking an aircraft.

*Stopway* - A rectangular area defined at the end of the available take-off run, prepared as a suitable area in which an aircraft can be stopped in the event of an abandoned take-off.

*Survey Control Point* - A monumented survey control point.

*Taxiway Element* - Elements of a runway include: taxiway, apron taxiway, rapid exit taxiway, and aircraft stand taxilane surfaces.

*Taxiway Guidance Line* - Guidance line painted on the surface of an aerodrome, typically a taxiway, deicing area, or apron.

*Taxiway Holding Position* – Marking painted at a position on a taxiway leading to a runway, intended to protect a runway, an obstacle limitation surface or an ILS/MLS critical /sensitive area at which taxiing aircraft and vehicles are expected to stop and hold unless otherwise authorized by the aerodrome control tower.

**Taxiway Intersection Marking** – A marking painted at a position at which taxiing aircraft and vehicles are expected to stop and hold until further cleared to proceed, when so instructed by aerodrome control tower. Marking and an airport surface protecting a non-runway location.

**Taxiway Shoulder** - An area adjacent to the edge of a taxiway pavement so as prepared to provide a transition between the taxiway and the adjacent surface.

**Touch Down Lift Off Area** - A load-bearing area on which a helicopter may land or take off.

**Vertical Line Structure** - Line structure of a defined vertical extent, which is located in an area extending from the edge of the runway to 90 m from the runway centerline and for all other parts of the aerodrome movement area to 50 m from the edge of the defined area.

**Vertical Point Structure** - Point structure of a defined vertical extent, which is located in an area extending from the edge of the runway to 90 m from the runway centerline and for all other parts of the aerodrome movement area to 50 m from the edge of the defined area.

**Vertical Polygonal Structure** - Polygonal structure of a defined vertical extent, which is located in an area extending from the edge of the runway to 90 m from the runway centerline and for all other parts of the aerodrome movement area to 50 m from the edge of the defined area.

**Water** - Water bodies close to the aerodrome movement area.

AMDB feature classes are structured into categories of elements, which are graphically transposed by points, lines, or polygons (Figure 5.12):

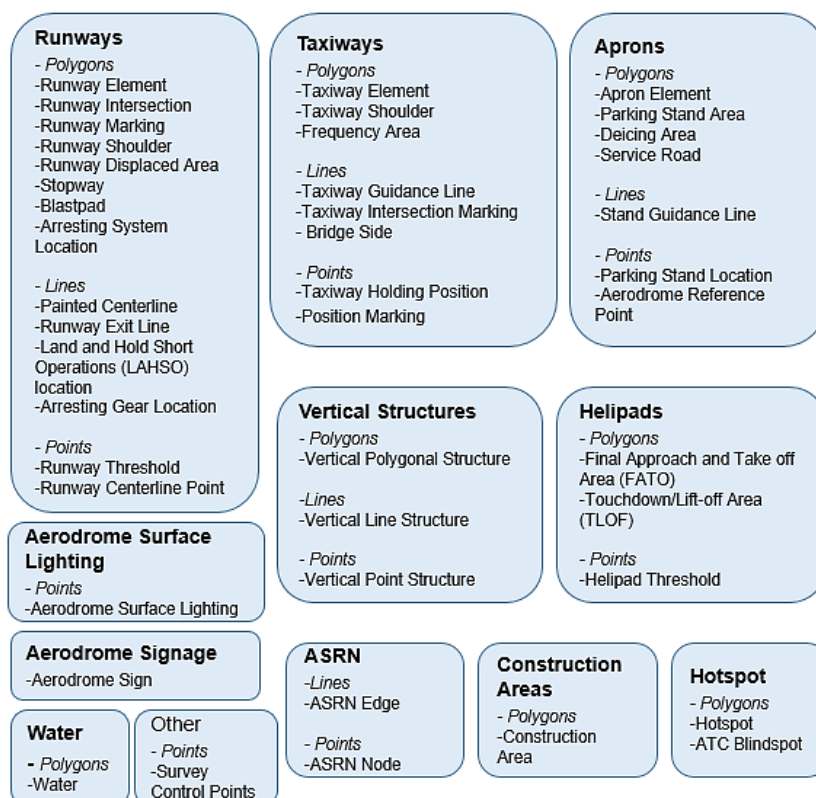


Figure 5.12. AMDB feature datasets

### 5.5.3. Data exchange

To perform data exchange, AMDB features are converted to Aerodrome Mapping Exchange Schema (AMXS) using the UML model, AMXM (Aerodrome Mapping Exchange Model).

AMXS (Aerodrome Mapping Exchange Schema) is the implementation in XML format of aerodrome mapping data, a standardized graphical coding, which includes metadata and data product specifications (Figure 5.13).

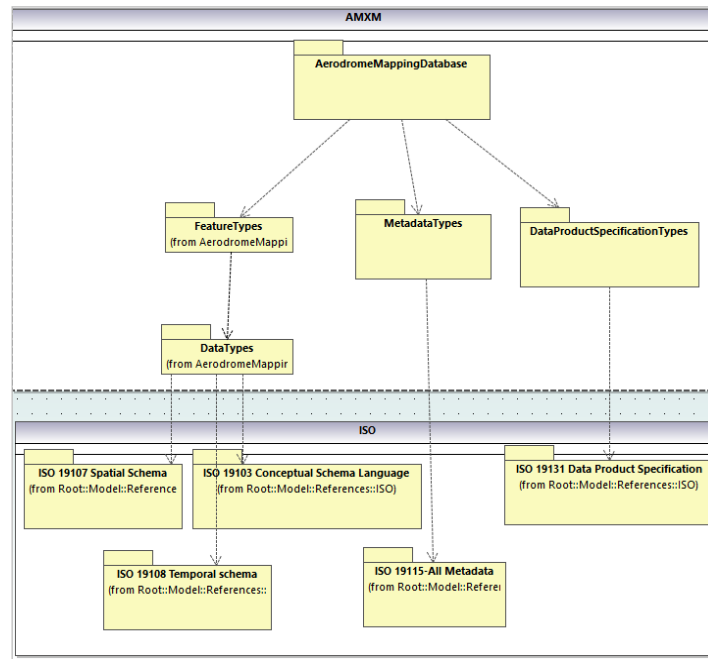


Figure 5.13. UML model for AMDB features, AMXM diagram using Altova UModel software

The AMXS schema ensures the interoperability of products, facilitating the processing of information by data integrators and ensuring consistency between operations.

The exchange of aerodrome mapping data is based on ISO19100 standards. The AMDB application schema provides the common data model for aerodrome mapping products, using UML representations.

## 5.6. Existing solutions for aeronautical information systems

### 5.6.1. GDMS platform

**GDMS** (Geospatial Data Management System) [33] developed by SLC Geomatic Solutions Ltd provides geospatial solutions and an extensive collection of tools designed for 3D modeling and analysis of protection surfaces around airports, spatial data processing, aeronautical data management and distribution, ensuring the exchange of data in AIXM 5.1 format:

- 3D analysis and modeling tools;
- Design of Obstacle Limitation Surfaces (OLS) according to ICAO Annex 14
- Design of terrain data and obstacle data collection surfaces, according to ICAO Annex 15

- Analysis tools for Obstacle Limitation surfaces (OLS) and terrain and obstacle data collection surfaces (eTOD);
- Management of electronic terrain and obstacle data;
- Templates for the production of aeronautical charts;
- Support for operational procedures;
- Both the Desktop and Online versions offer users the opportunity to access their saved models in their own workspace and to analyze obstacles for OLS and eTOD surfaces.

#### **5.6.1.1. Case study of Manchester International Airport, United Kingdom**

For this case study, I used the Desktop and Online versions of GDMS and tested them for the case study of Manchester International Airport in the United Kingdom, which serves as a basis for operations on two parallel runways, 05L / 23R and 05R / 23L.

#### **5.6.2. ESRI platform, ArcGIS for Aviation extension**

**ESRI** (Environmental Systems Research Institute) supports this industry by providing ArcGIS for Aviation: Airports and Charting extension [34]. ArcGIS Airports package includes:

- Validation of aeronautical data, part of the quality control process, so that the data can be subsequently used in analysis processes;
- 3D modeling of Obstacle Limitation Surfaces (OLS) and terrain and obstacle data collection surfaces (eTOD);
- Analysis tools for Obstacle Identification Surfaces (OIS);
- Management of electronic terrain and obstacle data;
- Adaptable workflows in accordance with the standards and regulations in force, for generating products intended for air navigation use;
- Production of aeronautical charts using templates;
- Data exchange using the AIXM format;
- Ensuring traceability.

#### **5.6.2.1. Case study of Manchester International Airport, United Kingdom**

For this case study, I tested the ArcGIS for Aviation extension for ArcGIS Desktop version 10.6.1 Advanced.

#### **5.6.3. Ascend xyz platform**

**Ascend XYZ** [35], in collaboration with ESA (European Space Agency), through the ARTES Integrated Telecommunications and Applications program, has developed a web application for keeping airports safe, with the following services and tools worth mentioning:

- Design of Obstacle Limitation Surfaces - OLS for the identification and evaluation of obstacles;

- Wildlife management by detecting environmental changes, using satellite images collected by Sentinel 2;
- Digitalization of operations and collecting information during periodic inspections on the airport movement area;
- Collector for wildlife activity from the airport perimeter, via Wildlife Registration application;
- Radar for wildlife detection inside OLS protection surfaces.

#### **5.6.4. IDS AirNAV platform, eTOD suite**

IDS AirNav, former IDS Air Navigation division of IDS Systems Engineering, was acquired by ENAV Group in 2019.

The solutions and services provided by IDS AirNav Platform [36] are described as follows:

- Design of obstacle limitation surfaces according to ICAO Annex 14
- Design of terrain and obstacle data collection surfaces, according to ICAO Annex 15
- Electronic Terrain and Obstacle Data Management (eTOD Airport Terrain and Obstacle Data Management);
- Data exchange using AIXM 5.1;
- Aeronautical information management, in accordance with ICAO and EUROCONTROL data quality requirements - ADQ (Aeronautical Data Quality);
- The transition from Aeronautical Information Services (AIS) to Aeronautical Information Management (AIM);
- Flight procedures and design of airspace, routes;
- Development and validation of operational procedures;
- GIS Charting and Aeronautical Information Publications (AIP) and Web services;
- Aeronautical charts templates;
- Real-time operational evaluation by control tower and cockpit simulator.

#### **5.6.5. Conclusions**

Among the existing solutions for the aviation industry, I considered GDMS and ArcGIS for Aviation for the case study of Manchester International Airport, and in order to compare their capabilities, I also included IDS AirNav and Ascend xyz solutions, identifying several criteria presented in Table 5.7.

Table 5.7. Comparative table between the capabilities of the studied aviation solutions

| Criteria                                               | GDMS | ESRI ArcGIS for Aviation | IDS AirNav | Ascend xyz |
|--------------------------------------------------------|------|--------------------------|------------|------------|
| Automating the design of OLS surfaces                  | ✓    | ✓                        | ✓          | ✓          |
| OLS analysis and obstacles evaluation                  | ✓    | ✓                        | ✓          | ✓          |
| Automating the design of eTOD surfaces                 | ✓    | ✓                        | ✓          | -          |
| eTOD analysis and obstacles evaluation                 | ✓    | ✓                        | ✓          | -          |
| Support for Aerodrome Mapping Database (AMDB)          | -    | ✓                        | ✓          | -          |
| Templates for aeronautical charts                      | ✓    | ✓                        | ✓          | -          |
| Support and 3D modeling tools                          | ✓    | ✓                        | ✓          | -          |
| DTM and DSM validation                                 | ✓    | ✓                        | ✓          | -          |
| 2D and 3D visualization                                | ✓    | ✓                        | ✓          | ✓          |
| Support for vector data, raster data and 3D models     | ✓    | ✓                        | ✓          | ✓          |
| Online version available without software installation | ✓    | ✓                        | ✓          | ✓          |
| Change detection for the protected airspace surfaces   | -    | -                        | -          | ✓          |
| Data exchange in AIXM format                           | ✓    | ✓                        | ✓          | -          |

As shown in the table above, ArcGIS for Aviation extension, IDS AirNav and GDMS solutions bring many tools for conducting aeronautical studies, with extensive 3D modeling capabilities of OLS and eTOD obstacle identification surfaces, obstacle assessment, templates for aeronautical charts, as well as a high degree of automation. In terms of data exchange, these solutions ensure interoperability through the AIXM data format, and in addition ArcGIS for Aviation and IDS AirNAV support AMDB.

### 5.7. Aeronautical Data Quality (ADQ)

Aeronautical data and information quality requirements for the Single European Sky (SES), in accordance with EU Regulation 73/2010[37] apply to related systems and procedures involved in the generation, production, storage, handling, processing, transfer and distribution of aeronautical data and information so as to support the interoperability of the European Air Traffic Management Network (EATMN), and the international standardization and harmonization requirements.

Aeronautical data and information include:

- Integrated Aeronautical Information Package (IAIP)
- Electronic terrain data
- Electronic obstacle data
- Aerodrome mapping data

According to EUROCONTROL specifications - Data Quality Requirements [38] and EUROCONTROL - ADQ Guidelines [39], RACR-AIS [25] and ICAO Doc 10066 PANS AIM [27], data quality describes the degree or level of confidence in the ability of the data provided to meet the data user's requirements in terms of accuracy, resolution, integrity, traceability, timeliness, completeness and format (Figure 5.14).

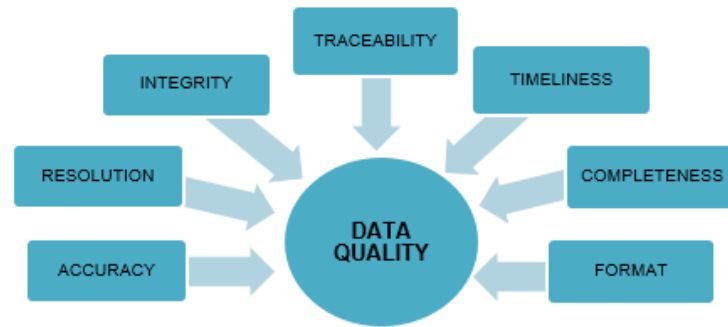


Figure 5.14. Aeronautical data quality

**"Accuracy** is the degree of conformance between the measured or estimated value and the true value." [25]

**"Resolution** refers to a number of units or digits to which a measured or calculated value is expressed and used." [25]

**"Integrity** is a degree of assurance that a data element and its value have not been lost or altered since the data origination or authorized amendment." [25]

**"Integrity classification (with reference to aeronautical data) - the classification is based on the potential risk resulting from the use of corrupted aeronautical data. Aeronautical data are classified as follows:**

a)routine aeronautical data: there is a very low probability when using corrupted essential data, that the continued safe flight and landing of an aircraft would be severely at risk, with the potential for catastrophe;

b)essential aeronautical data: there is a low probability when using corrupted essential data, that the continued safe flight and landing of an aircraft would be severely at risk, with the potential for catastrophe; and

c)critical aeronautical data: there is a high probability when using corrupted critical data, that the continued safe flight and landing of an aircraft would be severely at risk, with the potential for catastrophe;" [39]

**"Data traceability** is the ability to trace the course of data development, from its origin, processing history, to distribution and delivery." [25]

**"Data timeliness** is the degree of confidence that the data is applicable to the intended period of use." [25]

**"Completeness** is the degree of confidence that all the data necessary for the purpose of the project are provided." [25]

**"Data format** is a structure of data elements, records and files arranged to meet data quality standards, specifications or requirements." [25]

The aeronautical data quality standards were observed in the case studies in chapters 4.1, 4.2, 5.6 and 6 both for the input data and in the data processing, handling, transfer and distribution phases. The input data complies with all applicable regulations for ADQ. All processing procedures for input data are verified and validated in the quality control process, within the tolerance.

## Chapter 6. Integration of eTOD aeronautical studies and AMDB (Aerodrome Mapping Database) into a centralised database

### 6.1. Aerodrome Master Database - Centralised database for eTOD and AMDB

The online platform Aerodrome Master Database is SaaS - Software as a Service, which integrates eTOD and AMDB, in a centralised database.

The electronic Terrain and Obstacle Database (eTOD) and the Aerodrome Mapping Database (AMDB) support all activities and provide a common basis for designing flight procedures and producing aeronautical charts.

The integration of eTOD and AMDB in a single database has the advantage of creating a unique aeronautical data management system, workflows, data validation to ensure quality, as well as data exchange in the standardized format that ensures interoperability (Figure 6.1).

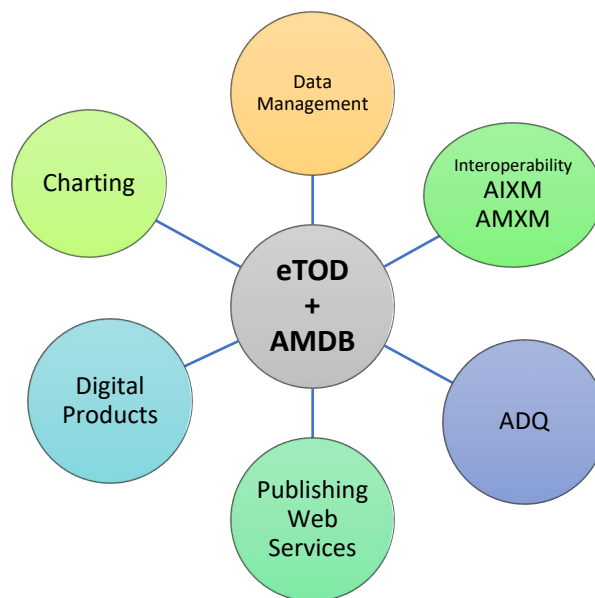


Figure 6.1. Services offered via Aerodrome Master Database online platform

Creating a spatial database primarily involves defining the coordinate systems in which entities operate.

According to ICAO standards, WGS 84 is the horizontal reference system, and the vertical reference system is referred to the mean sea level (MSL).

Coordinate transformations are required to make the conversion between the geocentric cartesian coordinate system to the geodetic coordinate system.

ICAO standards have been considered in the architecture of this database, from modelling the necessary features (Point, Line, Polygon Feature), the relations between these feature classes and the spatial constraints, in order to support the data exchange.

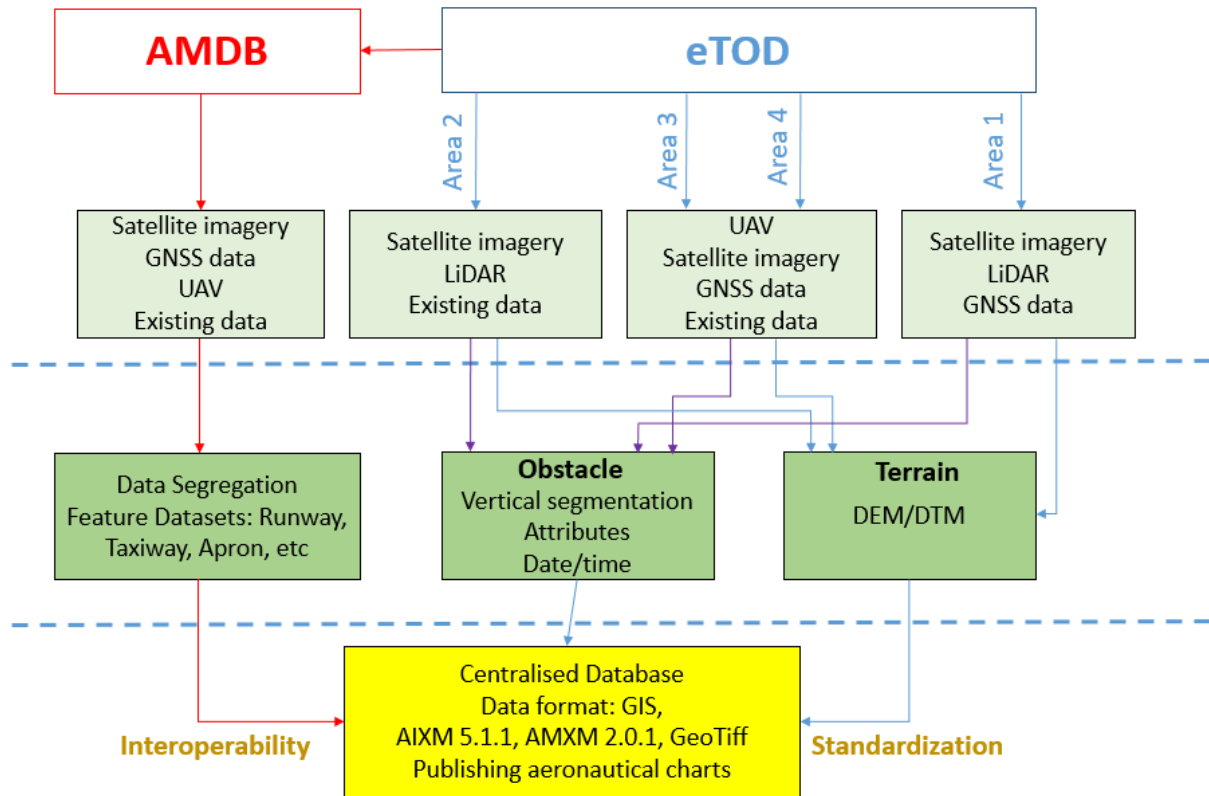


Figure 6.2. Centralized database for eTOD and AMDB

Spatial data acquisition and processing methods are customized in accordance with the purpose of the application, taking into account the specifications of each eTOD and AMDB area. (Figure 6.2).

Satellite imagery is one of the efficient ways to collect aeronautical data, in terms of its applicability to the area of interest with a large extent, as well as the speed of collection. GNSS data is required for the acquisition of GCP and for the verification and validation process, and it's also used to determine certain structures within Areas 3 and 4 and AMDB. Given the extent of eTOD surfaces, LiDAR acquisition is an alternative way to collect data with the best accuracy, but due to the high associated costs, it is usually suitable for larger projects. Photogrammetric methods using a UAV system are suitable for AMDB data collection and for eTOD Areas 3 and 4, complying with the accuracy requirements.

Given that the collected data comes from various sources and different methods of acquisition, it must be organized and managed in order to be integrated into information systems for analysis.

Due to the fact that the two products eTOD and AMDB have common elements (e.g. obstacle data), the data validation process may identify common geometries, but the textual attributes will be different for eTOD and AMDB.

Process automation and aeronautical data and information processing must be properly performed, using the appropriate methods for the purpose of providing critical and essential data elements, and related metadata.

Automating data validation reduces the risk of errors and at the same time ensures the provision of accurate, complete and current aeronautical data and information.

Automating the processes of 3D modeling of eTOD surfaces and identifying obstacles leads to increased reliability and optimized system performance.

Standardising data exchange is a key element in achieving global interoperability, so output data uses a variety of formats, including the AIXM format for eTOD and the AMXM format for AMDB, GeoTiff for terrain data, and the publication of aeronautical charts in GIS environment.

## 6.2. Modeling eTOD terrain and obstacle data collection surfaces

The project is carried out step by step to establish the four coverage areas for spatial data collection, terrain and obstacle data collection surfaces, the assessment of existing data and planning of subsequent data acquisition.

Using mathematical modeling, automation processes are proposed in order to design terrain and obstacles data collection surfaces and the identification of obstacles that penetrate these surfaces.

The data models are developed using GIS and sets of rules for implementing the workflows.

The models are developed for the generation of terrain and obstacle data collection surfaces (Coverage Areas), depending on the category of each runway, using ArcGIS Model Builder, through a system interface that automates information workflows through operations, in an iterative process.

The assembled methods and procedures for creating eTOD data models are organized into toolkits, grouped into a Geoprocessing model, that can be loaded into ArcToolbox.

Each eTOD area's geometry requires the creation of unique models with a set of tools corresponding to each area.

### 6.2.1. Data model for Area 1

Area 1 boundary identifies with the political boundary for the entire territory of the state.

I downloaded the administrative limits in shapefile format using Open Street Map service [40]. Area 1 boundary represents the polygon created by copying the administrative boundary of the state (Figure 6.3).

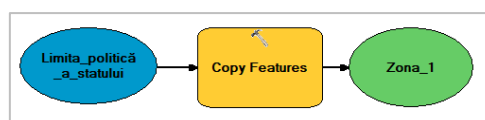


Figure 6.3. Data model for creating Area 1

### 6.2.2. Data model for Area 2

Area 2 has a high degree of complexity in creating the data model because it is divided into 4 areas with different specifications.

**Area 2a** is delimited by the runway strip and the clearway (Variable / input data), joining these two feature classes using Union 3D analysis tool (3DAnalyst Tool - 3DFeatures) (Figure 6.4).

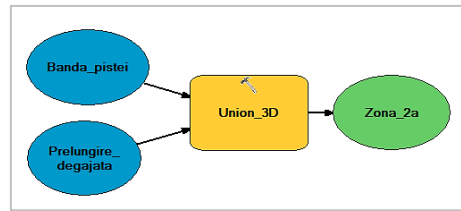


Figure 6.4. Data model for creating Area 2a

**Area 2b** is an area extending 10 km from the ends of Area 2a, in the direction of take-off, with a divergence of 15% on each side from the extended runway centerline and a 1.2% slope.

In order to create Area 2b, I used Python programming language. I created the following points AP1, AP2, AP3 and AP4 that define Area 2b, the planimetric coordinates and the elevation of AP1 and AP2 points are already determined, knowing the limit of Area 2a (the inner limit of Area 2b). The elevation of AP3 and AP4 points shall be determined using the elevation of AP1 and AP2 points, plus the length of the area that equals 10 km multiplied by a slope of 1,2%.

Knowing the length of the area and the divergence on each side with respect to the extended runway centerline, the extended width of Area 2b is determined. Thus, having the extended width of Area 2b and adding the width of Area 2a, the outer limit of Area 2b is determined. Knowing the inner and outer limit of Area 2b, the length and slope of the Area, the polygon for Area 2b is created.

**Area 2c** is an area extending 10 km outside Area 2a and Area 2b, with a slope of 1.2%.

In order to create Area 2c, I used Python programming language. I created circles with a radius of 10 km having the centers in the four points (corners) of Area 2a. Then I drew the tangents to these circles, applying the following rule that the length of the tangents should not exceed the length of Area 2a and then removed the outer tangents for the intersecting area. From the resulting product from the union of the 4 areas and tangents, I eliminated Areas 2a and 2b, and thus the polygon for Area 2c is created. The elevation of the outer limit of Area 2c is determined using the elevation of the inner limit (of Area 2a), applying the length of the area and the slope.

**Area 2d** is an area outside Areas 2a, 2b, 2c up to a distance of 45 km from the ARP (Aerodrome Reference Point), that intersects the limit of the terminal control area (TMA). Area 2d represents a horizontal plane, whose elevation is determined from the threshold with the minimum altitude, on a length of 10 km, with a slope of 1.2%.

Area 2d model is constructed starting from the polygons of Areas 2a, 2b and 2c already determined, which are joined by Merge (Data Management Tool - General), obtaining a new class of polygon type objects (Figure 6.5).

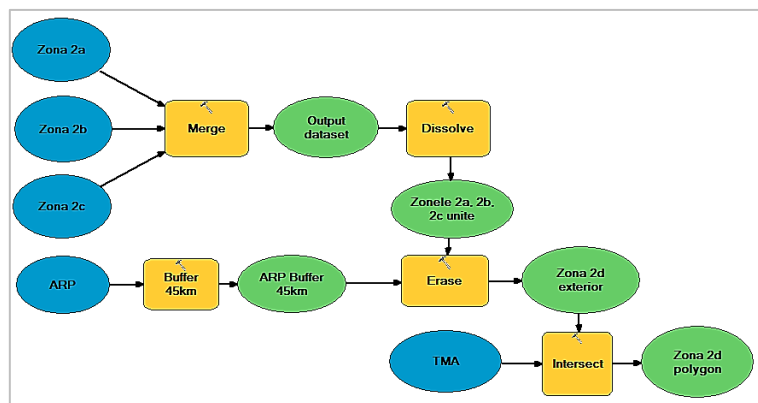


Figure 6.5. Data model for creating Area 2d

### 6.2.3. Data model for Area 3

Area 3 delimits the aerodrome movement area, by horizontal extension 90 m from the runway centerline and 50 m from the sides of other component surfaces. In the case of two or more runways, the boundary of Area 3 is common and results from the intersection of the specified areas.

The boundary of Area 3 is drawn using the runway centerline, runway boundaries, taxiways and aprons (Figure 6.6).

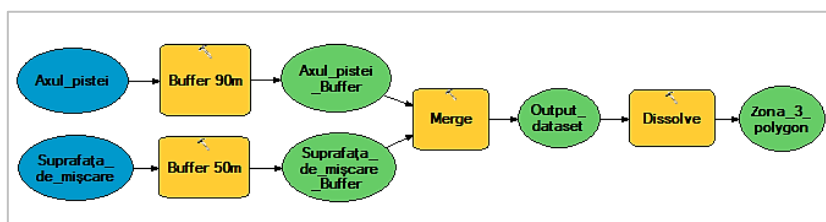


Figure 6.6. Data model for creating Area 3

### 6.2.4. Data model for Area 4

This data model is used for category II or III approach runways. Area 4 is represented by a rectangular area 900 m long from the runway threshold in the direction of take-off /landing and 60 m wide from the extended runway centerline (900 m x 120 m).

The classes of objects that are required to create this model are the runway centerline and the runway thresholds (Figure 6.7).

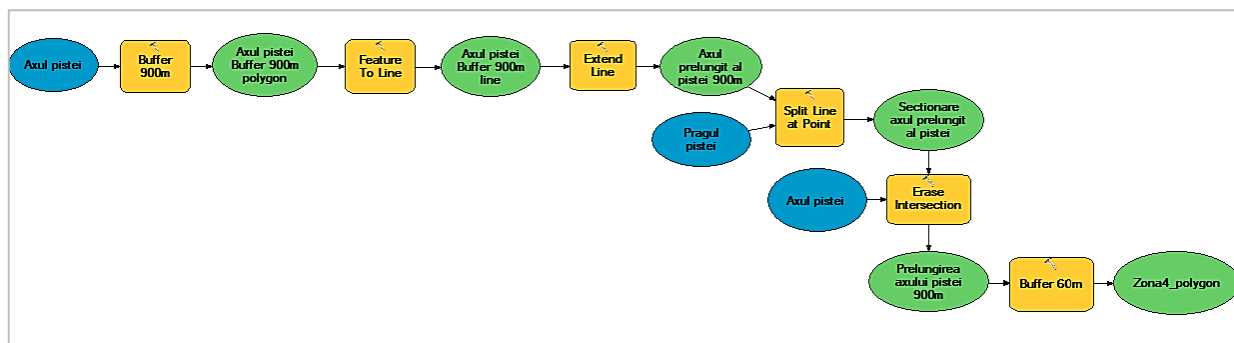


Figure 6.7. Data model for creating Area 4

The output of eTOD surface modeling is shown in Figure 6.8.

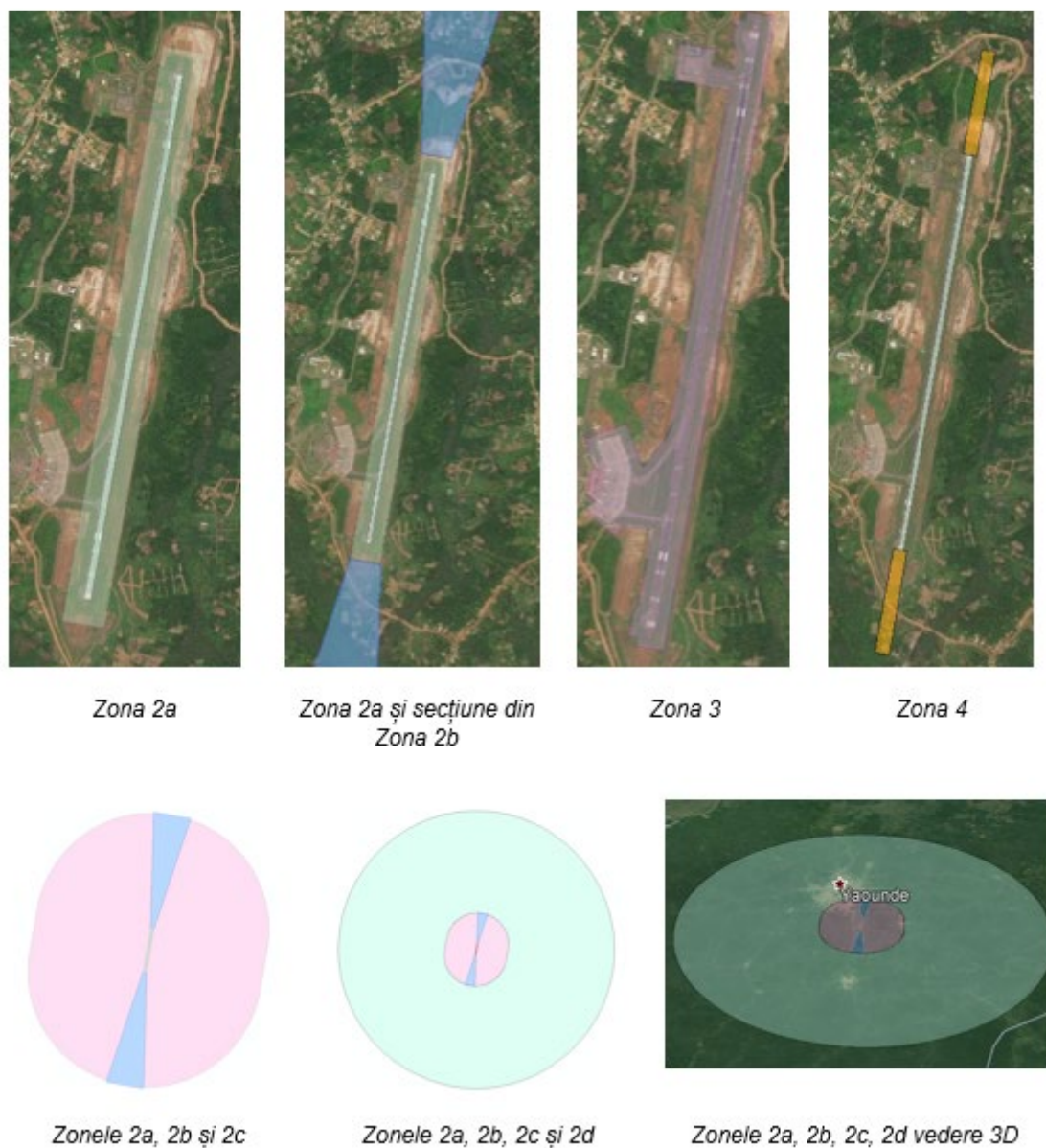


Figure 6.8. eTOD surface modeling results

### 6.3. Automation of the analysis process for identifying obstacles

Once the terrain and obstacle data collection surfaces are determined, the data model for obstacle assessment is created by intersecting the spatial data with these 3D surfaces. The spatial data subject to processing is adapted to the specifications of each area.

For Area 1, all objects whose height is over 100 m are identified (Figure 6.9).

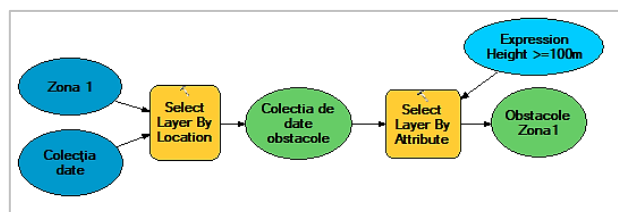


Figure 6.9. Data model for obstacles assessment within Area 1

For Area 2a, the objects that have a height of 3 m from the end of the runway, or the same elevation as the end of the runway, in the case of the sections related to the clearway, are identified (Figure 6.10).

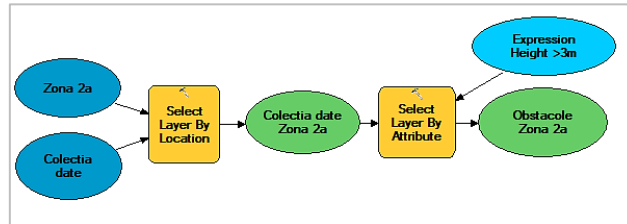


Figure 6.10. Data model for obstacles assessment within Area 2a

For Area 2b, the objects whose height is higher than 3 m from the ground are considered (Figure 6.11).

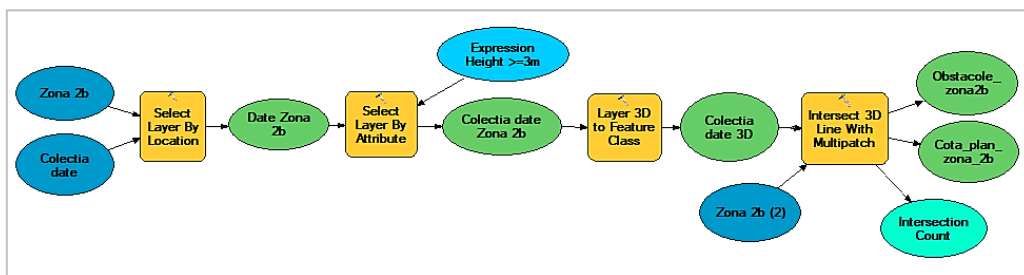


Figure 6.11. Data model for obstacles assessment within Area 2b

For Area 2c, the objects whose height is higher than 15 m from the ground are considered (Figure 6.12).

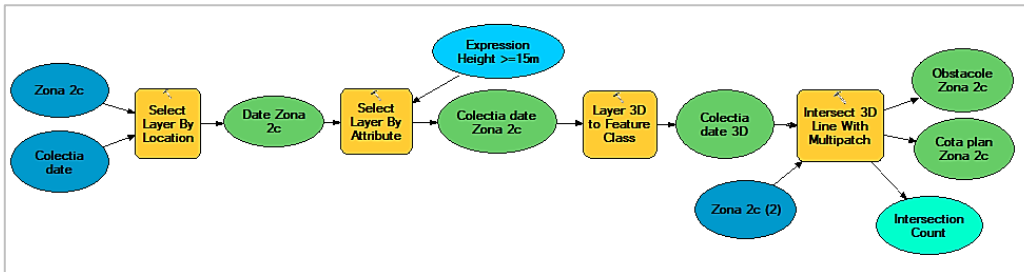


Figure 6.12. Data model for obstacles assessment within Area 2c

For Area 2d, the objects whose height is 100 m above the ground or higher are identified (Figure 6.13).

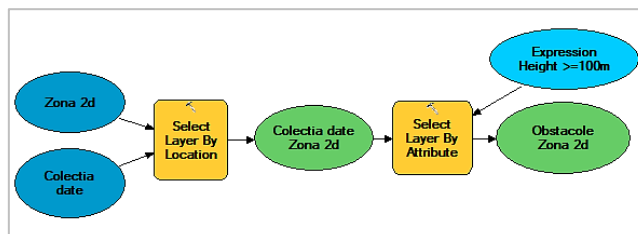


Figure 6.13. Data model for obstacles assessment within Area 2d

For Area 3, the objects that are included in the extended area 0.5 m above the horizontal plane passing through the nearest point located on the movement surface are identified (Figure 6.14).

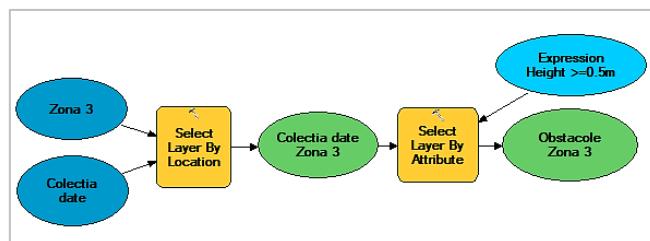


Figure 6.14. Data model for obstacle assessment within Area 3

The results of modeling the obstacle assessment process are shown in figure 6.15, draped on the orthomosaic.

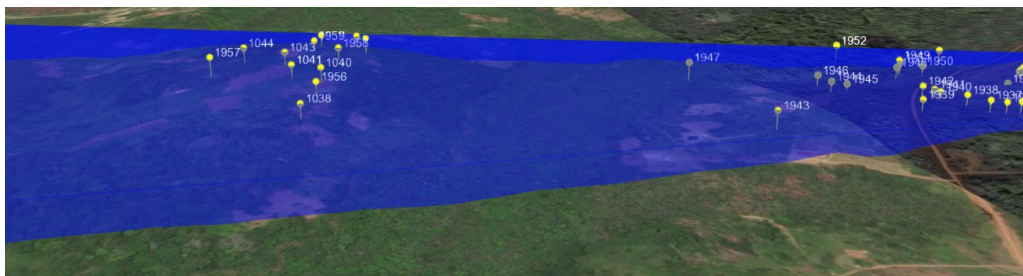


Figure 6.15. Results for modeling the obstacle assessment within Area 2b

|                             |                    |
|-----------------------------|--------------------|
| Area_of_coverage            | 2b                 |
| Data_originator_identifier  | Sabina Plavicheanu |
| Obstacle_identifier         | 1386               |
| Horizontal_accuracy         | 0.5                |
| Horizontal_confidence_level | 90                 |
| Description                 | HUT_L/C            |
| Horizontal_position_N       | 034444.0530N       |
| Horizontal_position_E       | 0113326.4531E      |
| Easting UTM32N              | 784059.184         |
| Northing UTM32N             | 414418.341         |
| Horizontal_resolution       | 0.00001            |
| Horizontal_extent           | <Null>             |
| Horizontal_reference_system | WGS84              |
| Elevation_top               | 707.885            |
| Vertical_accuracy           | 0.5                |
| Vertical_confidence_level   | 90                 |
| Elevation_reference         | MSL                |
| Vertical_resolution         | 0.001              |
| Vertical_reference_system   | EGM96              |
| Obstacle_type               | FIXED              |
| Geometry_type               | POLYGON            |
| Integrity                   | 0.00001            |
| Date                        | 6/30/2016          |
| Unit_of_measurement_used    | METRE              |
| Lighting                    | N                  |
| Markings                    | N                  |
| Pen                         | 5.549              |
| Area2b_elev                 | 702.336            |

Figure 6.16. The result of the obstacle analysis for Area 2b

Figure 6.16 shows the attributes according to Annex 15 of one of the obstacles penetrating Area 2b. The 'Pen' field represents the penetration amount in meters and 'Area2b\_elev' field represents the elevation of Area 2b plane in the point of infringement.

#### 6.4. Case study on implementing AMDB (Aerodrome Mapping Database) for Yaoundé - Nsimalen International Airport, Cameroon

Located 27 km south of the capital city, Yaoundé, the second busiest airport in Cameroon by total passenger traffic and the second largest, Yaoundé-Nsimalen International Airport operates on 01/19 runway non-precision, code 4 in direction 01 and precision approach category I, code 4 in direction 19.

#### **6.4.1. Spatial data used**

In order to produce an AMDB, spatial data is used in different formats (vector, raster, 3D models) that come from different sources:

- digital terrain models, derived by remote sensing methods from satellite images that have been georeferenced using GCP;
- high resolution orthomosaics;
- GNSS data;
- aeronautical charts and AIP information;
- CAD plans received from airport operators.

Spatial data must be transformed from the Cartesian coordinate system into a common datum, WGS-84.

#### **6.4.2. Workflows**

##### **6.4.2.1. Extracting and 3D modeling of geospatial information**

A high quality AMDB product requires the extraction or updating of 3D elements (according to the AIRAC cycle)<sup>1</sup> using orthophotoplanes and digital terrain models, a process that results in a large volume of data, which is managed in the GIS environment, within a database.

Each airport is unique, so certain AMDB data elements are not found within the perimeter of each airport. The 3D data elements created for FKYS are as follows, depending on the feature classes (Figure 6.17):

- **Runway:** Runway Element, Runway Threshold, Painted Centerline, Runway Centerline Point, Runway Marking, Runway Shoulder, Stopway, Blastpad, Runway Exit Line
- **Taxiway:** Taxiway Element, Taxiway Guidance Line, Taxiway Shoulder, Taxiway Holding Position, Frequency Area
- **Apron:** Apron Element, Parking Stand Area, Stand Guidance Line, Parking Stand Location, Aerodrome Reference Point, Service Road
- **Vertical Structures:** Vertical Point Structure, Vertical Line Structure, Vertical Polygonal Structure
- **Aerodrome Signage:** Aerodrome Sign
- **Aerodrome Surface Lighting:** Aerodrome Surface Lighting
- **Survey Control Point:** Survey Control Point
- **ASRN:** ASRN Node, ASRN Edge

Each data element is associated with a set of attributes; both the geometry and the related attributes are checked in the quality control process.

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<sup>1</sup>AIRAC - Aeronautical Information Regulation and Control; a cycle is predetermined every 28 days

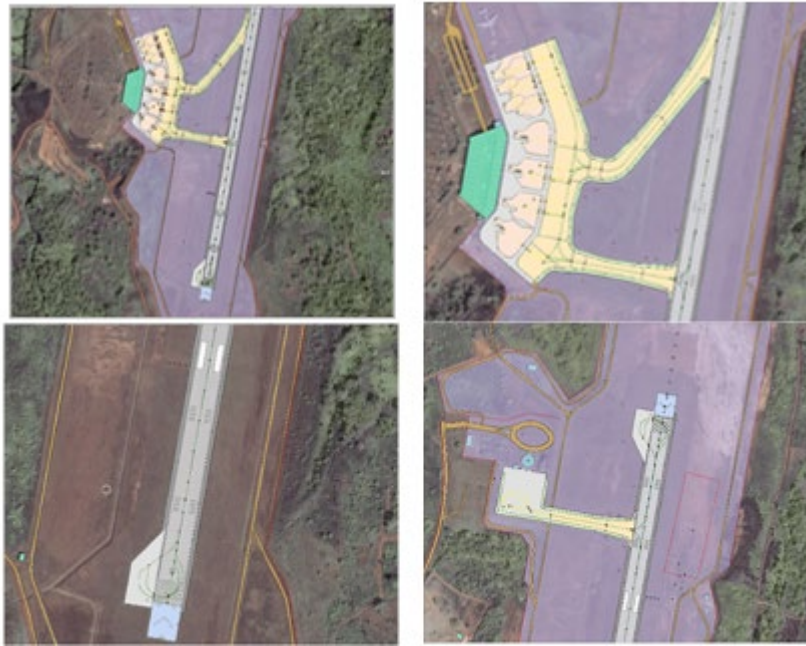


Figure 6.17. AMDB for FKYS International Airport, draped on high resolution orthomosaic

Figure 6.18 shows the workflow for AMDB data elements: information extraction and 3D modeling, populating the database with attributes, UML modeling using AMXM, and obtaining the schema for data exchange.

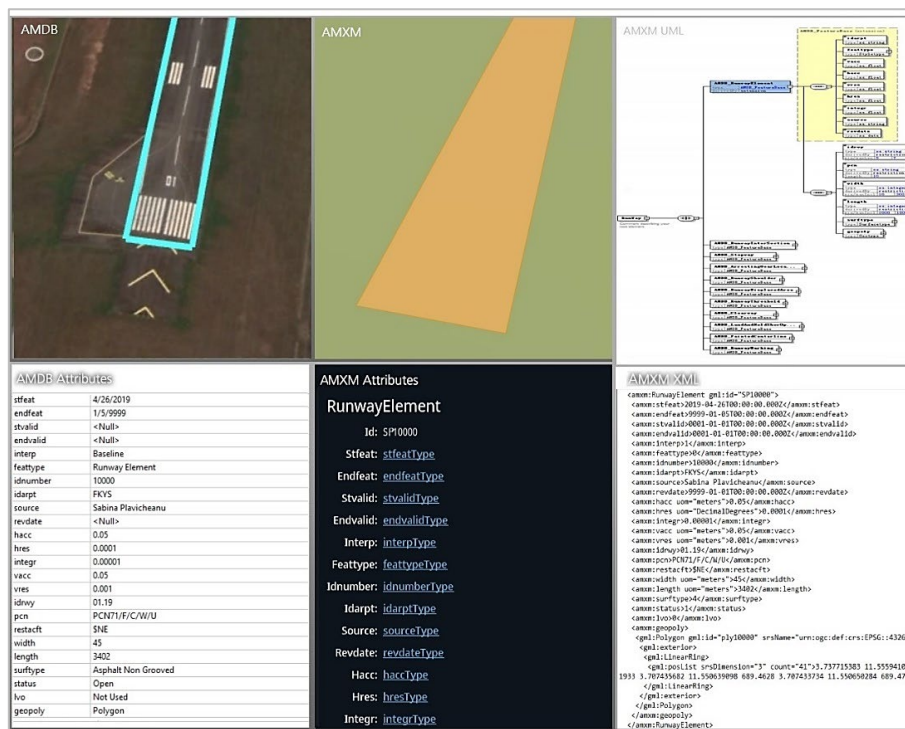


Figure 6.18. Workflow for modelling AMDB and AMXM schema

#### 6.4.2.2. Verification and validation

Verification and validation (V&V) is the critical process in any workflow, which confirms that the product corresponds in terms of geometric and functional constraints.



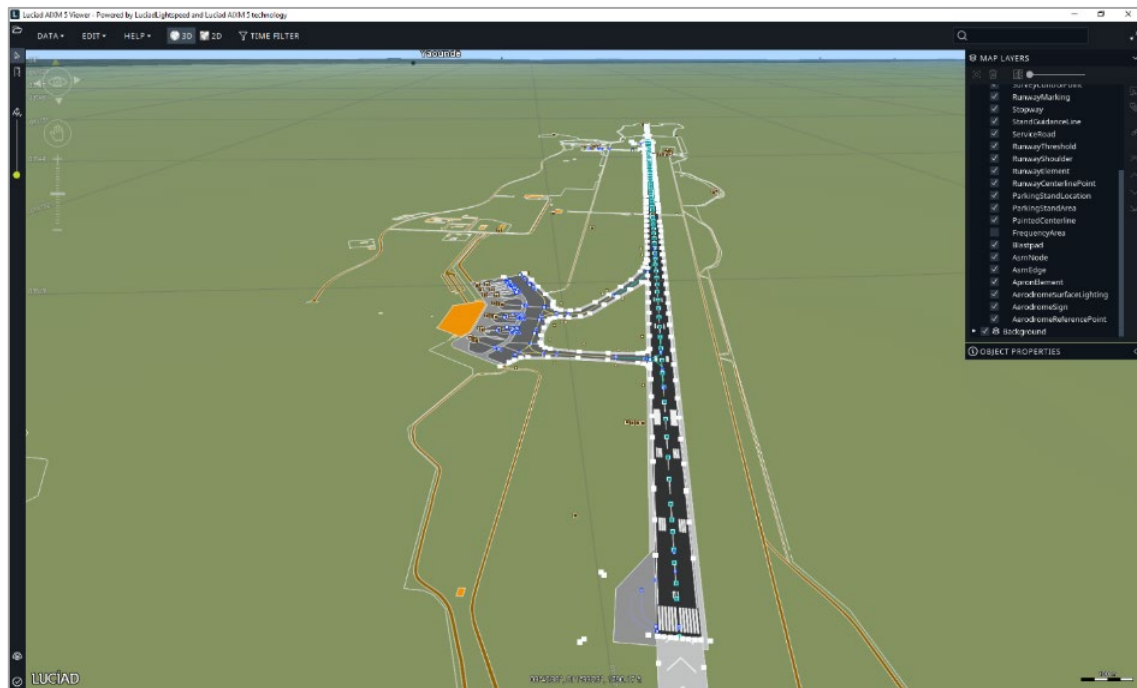


Figure 6.20. AMXM for FKYS International Airport using Luciad Lightspeed AIXM 5 Viewer software

## 6.5. Conclusions

The main purpose of this case study is to integrate the eTOD aeronautical studies and the AMDB aerodrome mapping database, two products, into a single database.

The workflow for integrating the two products is based on conceptualization by analyzing the structure of the eTOD database, the surfaces and how to test obstacles, as well as the structure of the AMDB database and the way aeronautical information is distributed.

With these aspects in mind, I designed the database, including:

- automation of eTOD terrain and obstacle data collection surfaces modeling
- automation of obstacle assessment
- automation of the verification and validation process
- automation of converting and transforming data elements into interoperable schemes.

The results of workflow automation confirm that the created models provide a high degree of confidence in identifying obstacles and determining the penetration amount for the eTOD protection surfaces.

This information is vital for designing the instrument flight procedures.

## **Chapter 7. Conclusions**

### **7.1. General considerations on the conducted research**

The need for and the importance of geospatial data is demonstrated by the growing requirement for up-to-date data to map the Earth's surface at any point on the globe. The collected spatial data depends on the purpose of the application, and data accuracy is essential for this industry. Therefore, it is necessary to work with validated methodologies.

Obtaining quality aeronautical data involves the use of complementing modern technologies, through data mergers, such as geodetic, photogrammetric and remote sensing methods.

The fast pace of technological progress facilitates the coverage and availability of images, satellites are collecting gradually more data, which leads to the need of optimizing data processing, exploitation and interpretation, and to increase storage space.

The development of various types of very high resolution sensors allow exploitation of digital terrain models derived from high quality satellite images, which are used in numerous databases, for various applications. Given the continuous development of these methods, the generation of digital models has become increasingly accessible.

Currently, the integration of satellite imagery processing and exploitation software and database design and implementation programs facilitates the extraction of spatial information. Process automation and updating geospatial databases, even in real time by accessing and storing data in the cloud (available via internet access) brings many advantages to the industry:

- Reducing execution time for repetitive activities;
- Reducing verification and validation time;
- Significant decrease in the percentage of errors, both in data processing and in the analysis and manipulation stages;
- High level of data quality and integrity;
- Efficient iteration of the analysis;
- Increase of productivity;
- Cost reduction.

The adoption of global standards for implementing spatial data infrastructure, by harmonizing workflows, brings many advantages through the creation, access and data exchange.

In order to implement an adequate and competitive information system, it is necessary to concentrate on the analysis and design phases. Visual modeling of geospatial databases can improve productivity. UML schemas created in the workspace help define models by eliminating manual implementation.

eTOD and AMDB are two independent products, the interoperable schemas for the distribution of aeronautical information are also different, AIXM 5.1.1 and AMXM 2.0.1.

This research demonstrates the need to integrate the aeronautical information into a single product. Adapting the complexity of existing software packages, products and solutions, as well as the cost to the capabilities, resources and capacity of smaller organizations, to achieve eTOD compliance, this application is designed in simplified steps to meet the needs of this industry, by facilitating processes at a reduced cost.

The solution presented for integrating eTOD and AMDB into a centralised database and automating workflows brings the following benefits:

- Represents a solution for optimizing the design of eTOD surfaces, obstacle assessment, ensuring and improving air traffic safety, in accordance with aviation regulations;
- Reducing data redundancy and errors;
- Optimization of airport operations by ensuring a low overall risk of accidents;
- Operational and strategic advantages;
- Better substantiation of the plan for expansion or modernization of airport areas;
- Increase the efficiency for planning flight routes, take-off and landing;
- Long-term sustainable development, through efficient measures, resource use, increased transport efficiency, linking national objectives with experience gained primarily in Europe, and internationally.

## **7.2. Personal contributions**

The complexity of the topic arises from the detailed analysis of spatial information in the context of airport safety, addressing multiple issues in case studies, from data acquisition, processing, validation, extraction and integration into a single solution, using the latest generation of technologies and software.

The subject of the thesis is relevant to the current situation in the field of aeronautical research, responding to the directives of ICAO global plan for air navigation GANP 2016 - 2030 aimed at the continuous development of safety and modernization of airspace, by implementing performance-based navigation procedures, which lead to a significant reduction in emissions and also the impact on the environment.

**The originality** of this paper is depicted by the implementation of an application that includes a single database for eTOD and AMDB, automating workflows for data processes and standardizing aeronautical information in UML schemes to ensure interoperability, which increases the performance of aviation safety systems.

This paper presents the first concept of implementing AMDB through the ICAO directives, adding the integration of the two products eTOD and AMDB in a single database.

The solution presented in this paper can be considered the support or foundation of the implementation of this system, both for Romanian airports and worldwide in order to attain an early alignment with the ICAO plan to improve aviation safety.

The interdisciplinary nature of this paper led to the combination of techniques specific to the fields of geodesy, remote sensing, photogrammetry, cartography, GIS, CAD, in other words geomatics, as well as computer science, programming, databases, with applicability in aviation, more precisely airport safety .

The personal contributions presented this paper as follows:

- 1) Aggregation of existing data and analysis of standards and regulations regarding aeronautical studies.
- 2) Analysis of photogrammetric and remote sensing methods for the acquisition and processing of spatial data, in order to conduct aeronautical studies.
- 3) Processing of SAR satellite images to detect changes within the protection surfaces around airports, the case study of Dubai International Airport, United Arab Emirates.
- 4) 3D change detection within the protection surfaces around airports, using optical satellite images, the case study of Dubai International Airport, United Arab Emirates.
- 5) Processing and exploiting optical satellite images for creating digital terrain models and orthomosaics, extracting spatial information for 3D modeling of buildings and integrating the data into spatial databases, the case study of Ras al-Khaimah International Airport, United Arab Emirates.
- 6) Evaluation of various existing solutions for aeronautical studies.
- 7) Identifying sectors with high potential for development and vulnerabilities of current solutions for aeronautical information management and aeronautical studies.
- 8) Extending the airport infrastructure model and protected airspace, derived from the current regulations, by designing a centralised database and integrating geospatial information.
- 9) Use of procedures for the management and analysis of geospatial information and design of databases for the aeronautical field.
- 10) Mathematical modeling in order to optimize the operations of assessment and ensuring aviation safety by:
  - a. automation of data validation processes;
  - b. automation of the eTOD 3D surface modeling process;
  - c. automation of the analysis process in order to identify obstacles;
  - d. automate the process of converting AMDB data elements into an interoperable scheme.

**The novelty elements** are a result of the research and the case studies, through the use of modern technologies and state-of-the-art software:

- Integration of eTOD and AMDB digital solutions and products in a centralised platform;
- Aeronautical information is available to all departments, accessing a single platform;
- Workflow automation for data validation;
- Automation of eTOD surfaces 3D modeling;
- Automation of the analysis process in order to identify obstacles;
- Updating the information and maintaining the database, the updated information becoming available in real time;
- Support for all operations (AIP, airport operations, airspace protection);
- Process automation of converting elements into interoperable schemas for the distribution of aeronautical information.

The proposed application is innovative from several points of view:

- Process: implementation of a significantly improved production and delivery method through integration and automation;
- Product: introduction of an improved product, which generates a new value for the customer / user / airport administration;
- Added value: improving existing products, services and processes;
- Services: reducing services delivery time, optimizing the allocation of resources, thus generating new revenues;
- Model: new methods to generate products, thus increasing system performance.

### **7.3. Perspectives on extending the research**

The conducted studies and the results obtained in this paper are a reference for future research. I propose the following perspectives on extending the research:

- 3D change detection for protection surfaces around airports using SAR satellite images collected by TerraSAR-X requires future research in the field of study, to streamline the analysis process, by processing data only in areas identified by the algorithm which have undergone changes.
- Perspectives for implementing an online platform concept, without the need to install additional software packages. The information would be available in the cloud and accessible directly from the browser, via internet connection.
- Due to the complexity of AMDB data elements, the automation of information extraction and creation of elements' boundaries cannot be achieved 100% as each airport is unique, so I propose for future research to focus on semi-automation for elements such as taxiways containing curved lines and markings of the taxiways and aprons, that change more often than other objects and the effort to update them is

significantly higher, whilst other elements such as runway markings are relatively easy to identify and automate using artificial intelligence.

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