CHAPTER 12

Photogrammetric Map Compilation

12.1 DIGITAL MAPPING DATA

The latter part of the 20th century brought an insatiable demand for georeferenced data. Not only does the business world now demand that information and statistics be geographically referenced, but the scientific and engineering industries do as well. Most digital data derived from aerial photography and other remote sensors will eventually find its way into georeferenced databases. Data from these and other sources can be earth registered, mixed and matched, and incorporated into Geographic Information Systems (GIS) for detailed analysis and solutions. Therefore, it is imperative for the project manager to understand the implications of data and coordinate systems, as well as methods of map data compilation.

12.2 COORDINATE SYSTEMS AND DATA

The demand for georeferenced data today is constant and touches all aspects of our daily life. It is therefore important to consider the potential uses of data sets and their respective coordinate systems and data. These choices affect the utility and accuracy of the final data set.

12.2.1 Coordinate Reference Systems

A coordinate reference system is an important consideration in a mapping project since it is a major factor in the accuracy of the mapping data set and should be specified with the chosen horizontal and vertical data.

North American Datum of 1927 (NAD 27) and National Geodetic Vertical Datum of 1929 (NGVD 29) are data that have been used throughout the United States for many years. They are the basis for many historical mapping data sets and are therefore still required for certain projects. The NAD 83 and North American Vertical Datum of 1988 (NAVD 88) are the most current horizontal and vertical reference datums used in the United States.

Conversion techniques between coordinate reference systems are mathematically feasible. Since this procedure may affect accuracy, it should be accomplished only by a fully qualified professional (i.e., geodisist or registered land surveyor).

12.2.2 Coordinate Systems

Data are referenced horizontally to one of several grid coordinate projection systems. Coordinates can be referenced to any desired geographic system, and the selected system is at the discretion of the user. This can be either a standard reference system to tie the mapping to the world or the state or an assumed grid reference pertinent only to the specific site.

It would be best to consider using standard coordinate systems for geographically registering information to facilitate comprehensive use of the data. This chapter will discuss three of the more universal grid systems accepted and commonly used in the United States. Selection of a datum for a project should consider end-user demands and accuracy.

An ideal situation would have an entire project in one segment of a selected datum; however, some projects do not lend themselves to this situation. Projects that involve an area that runs north/south for a long distance may cross datum segments. A common resolution to this problem can be to select one datum segment and extend it through the entire project. Obviously, this can cause horizontal accuracy issues that must be considered and understood. These issues should be discussed with a professional individual well versed in each datum and conversion.

12.2.2.1 Universal Transverse Mercator

UTM is a worldwide planar map projection that breaks the globe into 60 zones, each covering 6 degrees of longitude. UTM is a cylindrical envelope intersecting the earth along two lines that are parallel to a central meridian. This datum is commonly used for projects covering large areas. UTM grid structures are generally expressed in metric units and are tied to a reference datum (i.e., NAD 83). The United States is covered by UTM zones 10–20.

12.2.2.2 State Plane

The State Plane Coordinate System (SPCS) segregates 120 zones throughout the United States. Conformal conic projection can be used in states that are wide in the east–west direction. Transverse mercator projection can be used in states that are narrow in the east–west direction. These data are commonly used for projects falling within the boundaries of a specific state. The coordinates reference a specific SPCS along with an X and Y position in a plane and are expressed as “easting” and “northing,” respectively. The units may be expressed in United States feet or metric units.

SPCS-referenced projects that extend across state boundaries are sometimes necessary. When this situation is encountered, a common resolution is to choose one SPCS and zone and extend it throughout the entire project. In this situation horizontal errors will occur and should be understood; however, these errors are generally relatively small and can usually be accepted.

12.2.2.3 Latitude/Longitude

Latitude/longitude coordinates are not normally used on large-scale mapping projects, but they are common to small-scale projects covering large areas. If captured data are to be used in a national or international database, then this projection may be appropriate.

12.2.3 Vertical Data

The design of a mapping data set should always consider the vertical as well as the horizontal data, and accurate mapping databases must also be referenced to vertical data. Horizontal accuracy is affected by vertical accuracy. Therefore, the selection of the vertical datum is just as important as the selection of the horizontal datum. These vertical data are tied to a network of established ground points commonly called benchmarks.

NGVD 29 and NAVD 88 are the two most common vertical data used in the United States. A collection of benchmarks for NGVD 29 began in the 1850s and was first established in 1929 by the U.S. Coast and Geodetic Survey (USC&GS). Over time, the earth began to move and adjust, surveying methods changed and became more accurate (i.e., GPS), and NGVD points were continually obliterated by urban progress. A new set of points was established by the NGS, beginning in the late 1970s and completed in 1991. This new vertical datum is known as NAVD 88.

Adjustments have been made to NAVD since its inception, and care should be taken to note the desired adjustment for a specific mapping data set.

12.3 STRUCTURE OF DIGITAL DATA

Digital information that represents a map resides in a database matrix composed of a multitude of individual points. Each point is spatial, having a coordinate triplet value for X (easting), Y (northing), and Z (elevation).

12.3.1 Digital Data Generation

Mapping computer software does not "know" whether it is producing a contour or a building. It captures points and draws lines. To plot a map for human viewing, map features created by digital data generation must be described by a composite of several characteristics. Figure 12.1 schematically depicts the path of spatial information that is collected by a stereoplotter:

- Spatial (XYZ) data points, which form planimetric or topographic features, are generated by the stereoplotter.
- Generated data are stored within the data collector.

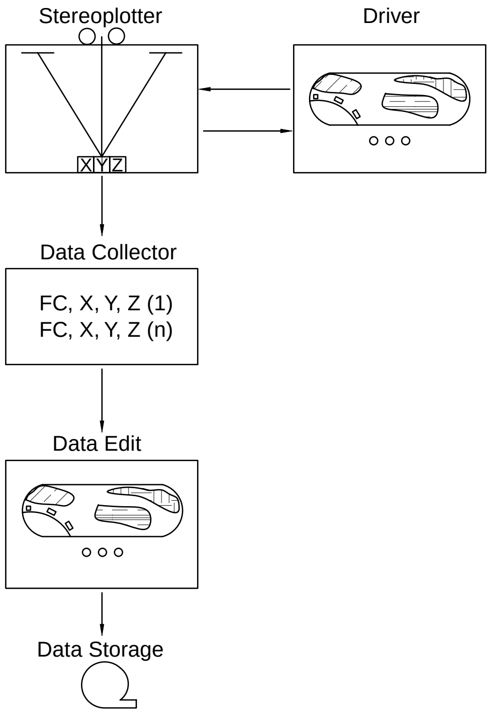

Figure 12.1 Schematic rendition of the path of spatial information that is collected by a stereoplotter.

- The created features appear on a monitor, in the form of mapping symbols, which is within view of the technician.
- Mapping data are output to peripheral editing, where a technician makes corrections to the database.
- Data can be output as hardcopy maps or on various electronic data media.

12.3.1.1 Feature Code

A feature code (FC) is an alpha/numeric character set that the computer recognizes as an identifier of a feature. This code directs the computer to an appropriate macro file.

12.3.1.2 Macro File

A macro file is composed of a set of instructions that controls the characteristics of a feature symbol. These instructions can pertain to line style, weight, and color, as well as any other specific symbol characteristics that are necessary to create the map feature.

12.3.1.3 Data String

A data string is a consecutive series of coordinate triplets (XYZ) which guides the computer in placing the feature in its true geographic location.

12.3.1.4 Data Form

This protocol readily permits differentiation of features when viewing the graphics screen or a data plot. The computer treats digital data as:

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FC, XYZ(1),.....,XYZ(n)
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12.3.2 Automated Feature Collection Methods

Advancements in software have changed the way data sets are collected. The project manager must be familiar with and understand the difference and importance of several other key terms:

1. *Cells* are planimetric features that have a standard shape and are repeated frequently throughout a mapping data set. They can be very intricate (i.e., a specific type of equipment) or very general (i.e., a utility pole). Mapping software can configure these cells into general groups sometimes known as cell libraries.
2. *Mass points* are points horizontally and vertically established on the mapping surface that depict a change in the vertical character of the surface (i.e., high or low spot on the ground).
3. *Breaklines* are unique, linear, topographic features that depict an abrupt change in the mapping surface (i.e., drainage patterns, edge of walls or roads, or cliffs). Breaklines define nonuniform character in the mapping surface.
4. The *Digital Elevation Model* (DEM) is a collection of evenly spaced elevation points that depict the mapping surface.
5. The *Digital Terrain Model* (DTM) is a collection of mass points and breaklines.
6. The *Triangulated Irregular Network* (TIN) is a surface model of triangular shapes created by the collection of DEM and DTM data.
7. *Contours* are lines of equal elevation on the mapping surface.

12.3.3 Data Collection

Data collection can generally be divided into three basic categories.

12.3.3.1 Planimetric Features

Cultural details are generally considered to be structures, road networks, edges of water bodies, utilities, transportation facilities, etc.

12.3.3.2 Topographic Features

Terrain characteristics are considered to be changes in the elevation of the Earth's surface.

12.3.3.3 Annotation

Attributions include textural information that describes the planimetric or topographic features. The planimetric feature annotation may include street names, building numbers, or the type of construction. The topographic feature attribution may include the horizontal and vertical location of the feature (i.e., elevation 510 ft).

12.4 ADVANCEMENTS IN MAP COMPILATION

Current advancements in map compilation software have improved the efficiency and accuracy of feature data collection.

Linear feature recognition software is capable of recognizing and automatically plotting certain planimetric features such as road networks and edges of water bodies. The success of these types of software depends largely on the quality of the source imagery and the desired features to be collected.

The collection of common, often repeatable planimetric features (i.e., certain building types or utilities) with the use of cells and cell libraries can speed the process and in some cases eliminate errors.

Software that makes use of DEM, DTM, and TIN data sets to generate cross-sections and contours also can expedite data collection and minimize errors.

12.4.1 Elevation Data Collection Methods

Elevation data are generally collected as a combination of mass points and breaklines and is processed through specific software to generate data sets such as TIN and contours. Today, end users of elevation information utilize data sets for analysis and design.

See Figure 12.2 for a scheme of mass points and breaklines.

1. Mass points can be created in one of two methods:
   a. A pattern of points, either random or on a grid, can be read on a stereoplotter or softcopy.
   b. A process of autocorrelation can be implemented so that the computer generates a grid of spatial points.
2. Breaklines are strings of individual spatial points read on a stereoplotter or softcopy following abrupt terrain change features.

Figure 12.3 depicts the contours created using the mass points and breaklines seen in Figure 12.2.

12.4.2 Planimetric Feature Collection Methods*

Planimetric features such as buildings, utilities, roads, water body boundaries, and edges of tree lines are collected by viewing imagery and collecting a series of points

* Chapter 14 in *Aerial Mapping: Methods and Application* (Lewis Publishers, Boca Raton, FL, 1995) presents a broader version of data collection.

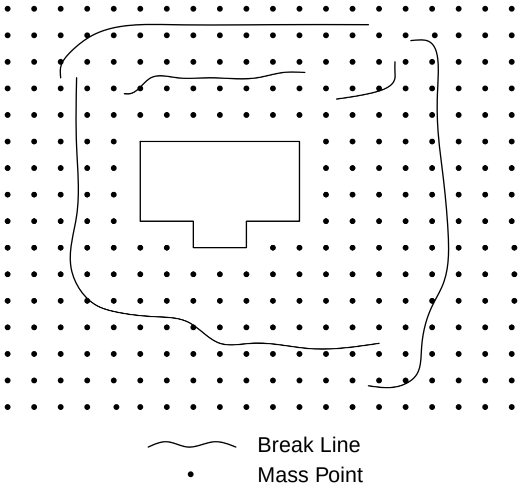

Figure 12.2 A scheme of mass points and breaklines.

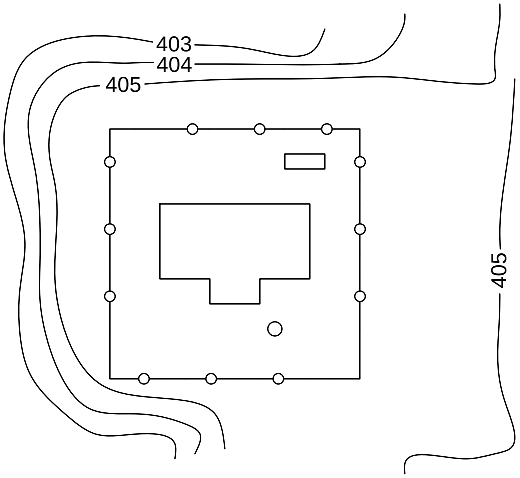

Figure 12.3 Contours created from mass points and breaklines.

that describe the location and shape of the feature. The data point stream that delimits the shape of the feature is accompanied by factors that identify it — line weight, style, and color, as well as any other factors that further characterize the feature.

Many of these planimetric features can also be collected with the aid of linear feature recognition software. This technology is still under various stages of development, and its success depends to a great degree on very high quality imagery in order to distinguish selected features to be collected. Feature recognition software requires the use of digital imagery and softcopy compilation. Generally, the process involves the selection of a typical group of pixels that represent a feature (i.e., a paved road surface). The software is then directed to follow a certain pattern and find pixels that are the same as those selected. The software then generates a prescribed pattern for the feature noted.

12.5 DATA STANDARDS

Feature standards have been developed and adopted by most major mapping firms and by federal and state agencies. Features of constant shape, called cells, were increasingly used in mapping features such as fence and tree lines, utility poles, and railroad tracks. Standard line weights, colors, and patterns were developed. The use of geospatial data in virtually every part of our lives at home and work has demanded a common set of standards for spatial data. The federal government has developed the Federal Geospatial Data Standards, and these standards are becoming the default standards for the photogrammetric mapping industry. A successful project manager will include the appropriate set of mapping standards in the scope of work for any photogrammetric mapping project.

12.6 DIGITAL MAPPING DATA FLOW

Successful project managers of photogrammetric mapping projects need not comprehend the mathematical equations that are the basis for stereodigital data collection. However, they should have a general understanding of the basic principles and work flow. Figure 12.4 shows a general stereoimage collection work flow chart.

12.6.1 Project Planning

A successful stereocompilation project should begin with a set of goals, including the expected end products, level of detail required, standards, horizontal and vertical accuracy, and final data media. These goals can be achieved by writing an adequate scope of work that clearly defines the end results, but does not dictate methodology:

- End products
  - Planimetric and topographic maps
- Level of detail required
  - 1 in. = 100 ft with 2-ft contours
- Standards
  - FGDC spatial data standards
- Accuracy requirements
  - ASPRS Class 1 standards
- Final media
  - Digital data on CDROM
  - Hardcopy on bond paper

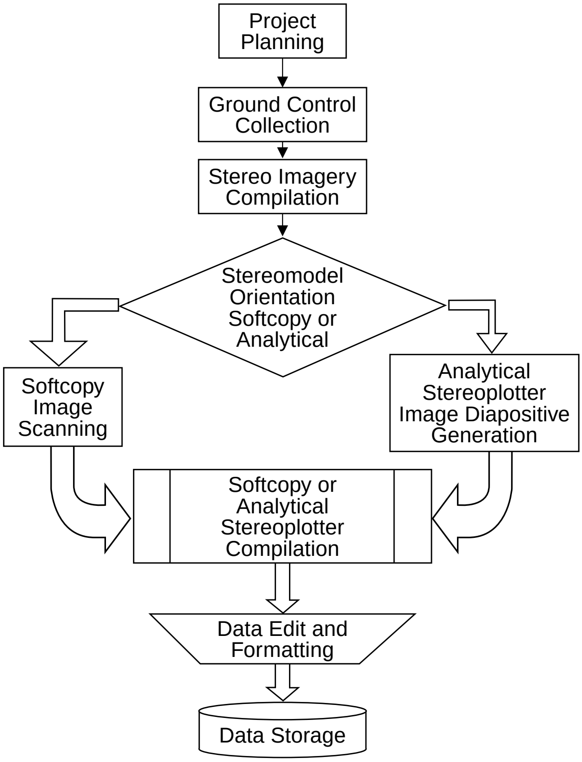

Figure 12.4 Stereoimage collection work flow chart.

12.6.2 Ground Control Collection

Ground control installation should be accomplished by methods that meet the accuracy requirements for the final mapping products only. Survey efforts such as permanent retrievable control points for many mapping projects may not be required and generally should not be specified in planning and scope of work development. The amount of ground control required and its accuracy are tied to the mapping accuracy requirements. Therefore, the methods used for ground survey collection, number and location of points, etc. may not need to be specified. These details should be left to qualified professionals such as the photogrammetry firm professionals who will accomplish the mapping.

12.6.3 Imagery Collection

For the purpose of this chapter, imagery collection will be assumed as utilizing new near-vertical aerial photography. However, some projects may allow for the purchase of existing photography or other sensor type data to be used for the final mapping data set. Imagery type, camera lens focal length, negative scale, and coverage should be clearly understood:

- Imagery type
  - Black and white
  - Natural color
  - Color infrared
- Camera and photo scale
  - Flown with a 6-in. focal length metric camera
  - Near-vertical photography at 1 in. = 300 ft negative scale
  - Flow with 60% forward lap and 30% sidelap
- Photo coverage
  - Photo coverage as shown on USGS 7.5 ft quad sheets

12.6.4 Stereomodel Orientation

The next major phase in the mapping process is orientation of the imagery to the Earth's surface by using the ground control collected for the project. This process is most often accomplished today with the use of aerotriangulation software (see Chapter 11 for more detail).

Stereomodel orientation consists of:

- Adjustment of imagery to correct camera alignment to see in three dimensions
- Adjustment of the imagery to the earth's surface
- Adjustment of the imagery to ground control

12.6.5 Digital Data Stereocompilation

Currently, the mapping industry is moving toward a total softcopy mapping environment. Softcopy mapping system hardware is generally less costly than the conventional analytical stereoplotters of the 1990s. The efficiency of software coupled with the increased speed of microprocessors has made the feature collection accuracy and speed comparable with that of conventional analytical stereoplotters. When capturing digital data with an analytical stereoplotter, the mapping instrument is interfaced with a driver computer that controls the actions of the mapping instrument. Digital data are then exported to a data collector.

Softcopy stereoplotting systems incorporate a high-resolution scanner, a large format/high-resolution monitor, a high-speed computer processor, and large data storage media with software capable of viewing digital imagery in three dimensions with the aid of special glasses. A suite of software allows for the viewing and compiling of features from digital imagery provided from high-resolution scans of original processed aerial film.

Digital mapping with an analytical stereoplotter or softcopy workstation involves a series of operations for both planimetric and topographic feature collection.

12.6.5.1 Planimetric Features

Planimetric (cultural) data are generated by drawing cultural features that are visible and identifiable on the image. Within the stereoplotter there is a visible reference mark. To draw an object the operator must position this reference mark on the apparent elevation of that feature. Since mapping is accomplished by utilizing

Table 12.1 Common Planimetric Features which Are Present in a Digital Database

Airports	Footpaths	Railroads
Alleys	Golf courses	Reservoirs
Athletic fields	Guardrails	Rivers
Barriers	Hydrants	Roads
Billboards	Inlets	Ruins
Borrow pits	Jetties	Sidewalks
Bridges	Lakes	Sign posts
Buildings	Light standards	Single trees
Canals	Mail boxes	Streams
Catch basins	Manholes	Streets
Cemeteries	Orchards	Substations
Churches	Parking lots	Swamps
Dams	Parks	Tanks
Ditches	Piers	Telephone poles
Driveways	Pipelines	Towers
Dwellings	Plantations	Trails
Fences	Pools	Walls
Field lines	Power structures	Wharves
Flag poles	Quarries	Woodlands

a spatial image, the mark must be at its true elevation for the observed point to be in its true horizontal position.

Unless otherwise specified, compilers map all planimetric features that are compatible with the mapping scale. On large-scale photos, various cultural features can be identified. A list of these features would include, but would not be limited to, those tabulated in Table 12.1. The compilation technician must also know and utilize the symbology and scheme that is called out in the scope of work for a project:

- Plot all features visible and identifiable on the imagery
  - Depends upon the imagery scale and project specifications
- Symbology and scheme
  - Specifications should note required symbology
  - Feature layers required (scheme) should be clearly spelled out in the scope of work

12.6.5.2 Topographic Features

Data necessary to create contours are collected by the process of DTM and by TIN generation. Contour intervals should be known and addressed in the scope of work prior to collection. Selected mass points are also collected to model surface area that is not typical (i.e., high and low areas). These types of points are placed individually by the compilation technician and are therefore generally more accurate than computer-generated points (DEM) and contour lines.

To obtain contour and elevation data:

- Automatically generate a DEM
- Generate mass points and breaklines where necessary (DTM)
- Review stereomodels and add any required additional points and breaklines to define irregular areas

12.6.5.3 Data Scheme

Digital data are usually separated into "layers," with each data layer containing specific information for related features. Today this is generally called a data scheme. Many data sets are used in a GIS or are stored for use at some later time. The data scheme greatly affects the effectiveness of a data set in a GIS. Individual layers contain information concerning contours, transportation, hydrology, photo control point locations, map compilation boundaries, vegetation, transmission lines, surface utilities, underground utilities, political boundaries, buildings, text annotations, and other information essential to fulfilling the demands of a query. The scheme to be used should be specified in the scope of work.

The federal government has developed a broad set of data scheme known as the Federal Geodetic Data Committee Spatial Data Standards (FGDC-SDS). These standards are available to the public and have been developed with experts in the mapping industry. In lieu of other unique project scheme standards, FGDC-SDS may be employed.

12.6.5.4 Digital Data Edit

In a state-of-the-art photogrammetric mapping office today, editing is generally divided into two parts:

- Quality control of the mapping products. Most analytical and softcopy workstations today are capable of viewing feature vector data (i.e., roads, structures, contours, elevation points, etc.) overlaying the imagery. This software feature allows for a thorough review of the data collected. One method of checking elevation data is accomplished by generating contours from the elevation points collected. The contours are then superimposed over the imagery, and the editing technician checks to make sure that they accurately depict the character of the ground and are attributed properly. Planimetric feature data collection quality control is also best checked with the aid of superimposition over the imagery.
- Graphic editing and final formatting of the data sets. Graphic editing is generally considered to be the final attribution of files, sheeting, and formatting. Attribution may include margin and legend information, tic and grid marks, building and street names, and contour labels. Many projects will always require hardcopy maps with preset sheet formats, borders, and title blocks. The graphic editing technician prepares files for these types of products and formats the digital data sets in the required software format, such as Intergraph, Arc Info, or AutoCAD. The graphic editing technician then creates the final hard- and softcopy data sets for delivery.

Data Editing
Quality control checks
Planimetric data
Topographic data
Graphic editing
Attribution
Sheeting
Final data formatting

12.6.6 Ancillary Data Collection

The demand for spatial data today has also increased the necessity for secondary spatial data. A secondary spatial data set contains information that is generated from the primary planimetric and/or topographic data sets. Many engineering, planning, and environmental projects demand the capability of geospatially accurate planimetric and topographic data to provide answers to queries. Volumes, centroids, areas, and linear distances are all easily calculated from geospatially accurate data sets. Today, software packages allow the photogrammetric technicians to compile these types of data as they collect the features. When these demands are known at the beginning of a project, the effort to collect the information and the associated cost can be minimized. Again, spending the time to create an accurate set of specifications that clearly spells out the required data sets is imperative to the project manager.

12.6.7 U.S. Geological Survey Data

The USGS stocks a number of products available to the public.

Millions of aerial photos within the confines of the United States and images covering the world from several series of remote sensing satellites are stored at the EROS Data Center. Queries can be directed to:

U.S. Geological Survey
EROS Data Center
47914 252nd Street
Sioux Falls, SD 57198-0001
Tel: 800-252-4547 or 605-594-6151

A list of US GeoData products — digital line graphs (DLG), digital orthophoto quads (DOQ), digital raster graphs (DRG), and digital elevation models (DEM) — is located by an on-line search of the key phrase “global land information.”

USGS quadrangle sheets of various scales can be purchased from numerous dealers or from the Rocky Mountain Mapping Center. Log on to the web site http://mapping.usgs.gov/mac/maplists.html for a list of the obtainable maps. This reference tells how to locate map sheets by state or specific sheet name or by latitude/longitude, and is also a guide to local distributors.