Spatial Data Considerations for Civil Engineers

Earl F. Burkholder, PS, PE, F.ASCE
President, Global COGO, Inc.

http://www.globalcogo.com

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Spatial Data Considerations for Civil Engineers

Earl F. Burkholder:

- Member of ASCE since 1972.
- Taught surveying at NMSU 1998 to 2010.
- Wrote “The 3-D Global Spatial Data Model”
- Current Secretary of Geomatics Division ASCE
- 2010 ASCE Surveying & Mapping Award
  - October 22, 2010
  - ASCE Annual Meeting, Las Vegas, Nev.
Meeting Theme - Mission Possible:

- Sustainability in the Desert Southwest
- Permanence of location is related to:
  - Geography, knowing where things are.
  - Geometry and geometrical relationships.
  - Geodesy and spatial data accuracy.
  - Measurement; technology and tools.
  - 3-D digital spatial data
  - bits, bytes, binary, ASCII, and www.
Spatial Data Considerations for Civil Engineers

**Mission Impossible:**
- “Get it” all the first time.
- Arrive at a goal without benefit of the journey.

**Assumptions:**
- Civil Engineers need/use spatial data.
- Not everyone learns surveying in college.
- Engineers and technicians know geometry.
- New technology facilitates productivity.
- Learning can be enjoyable if resources are available and if information is well organized.

What does it take to increase productivity?
I need to gage the audience:

- What does it take to keep us on same page?
- I presume many are sophisticated users.
  - Technicians can be geometrical whizzes.
  - Professionals are more concept oriented.
- Talk is balance between abstract/practical.
- My comments may be impractical & futuristic.
- Web links are included for additional study.
- Full paper is printed in the proceedings.
Let’s talk about SPATIAL DATA – Surveying

- Maps, geometry, and coordinates.
- Flat Earth and limiting assumptions.
- Datums – horizontal and vertical.

“3-D Datum for a 3-D World” article in Geospatial Data Solutions, May 2004

- Geographic Information Systems (GIS).
  Universal data storage system – 3-D?

- Spatial data accuracy – How good (reliable) are the data? Consequences of bad data?
What is the Global Spatial Data Model (GSDM)?

- The GSDM is an arrangement of existing geometrical elements and concepts.
- GSDM is based on the DoD Earth-centered Earth-fixed (ECEF) geocentric coordinates.
- GSDM is equally applicable:
  - Worldwide with same set of equations.
  - In any discipline using spatial data.
- Fully supports 3-D digital spatial data.
- The GSDM contains no secrets.
The BURKORD™ 3-D Diagram

1. Geocentric Coordinates: X, Y, Z
   - True 3D, Computations follow rules of solid geometry
   - Linear adjustment model
   - Meter length units

2. Geodetic Coordinates + Ellipsoid Heights
   (Units of Degrees, Minutes and Seconds) (meter length units)

3. Geocentric Coordinate Differences
   - \( \Delta X, \Delta Y, \Delta Z \) (Meters)
   - GPS Results

4. Geoid Heights
   Geoid Height Differ.

5. Curvature and Refraction

6. Rotation Matrix

7. Local Geodetic Horizon Coordinate Differences:
   - \( \Delta e, \Delta n, \Delta u \) (Meters)

8. Geodetic Coordinates + Orthometric Heights

9. (Pseudo 3-D Coordinates)
   State Plane (Map Projection)
   Orthometric Coordinates (Leveling)

10. P.O.B. Datum Coordinates:
    - (feet/meters)
    - Survey plots

11. Mark-to-Mark (Total Station) Observations
    - Slope distances
    - Azimuths
    - Zenith directions

12. Project Datum or Surface Coordinates

13. True 3-D Spatial Data

2-D Horizontal + 1-D Vertical
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Three useful coordinate systems - I

- **Geodetic Coordinates:**
  - Latitude, angular distance from Equator.
  - Longitude, angular value from Greenwich.
  - Ellipsoid height above or below ellipsoid.

- **Geocentric ECEF Metric Coordinates:**
  - Origin at Earth’s center of mass.
  - X & Y, plane of Equator, X at Greenwich.
  - Z is parallel with spin axis of Earth.
  - Rectangular coordinates & solid geometry.
  - Work with coordinate differences.

Three useful coordinate systems - II

• Local – state plane or other well-defined:
  - East/north/up is right-handed.
  - North/east/up is left-handed. Either is OK.
  - Be careful with flat-Earth assumption!

• Low distortion projection:
  - Becoming popular, but not recommended because it is a 2-D model. Elevations need to be handled separately.

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Types of Spatial Data

• Absolute values are coordinates in a well-defined system, X/Y/Z or east/north/up.

• Relative values are differences within the same system.
  - GIS data bases use absolute coordinates.
  - Engineers work with measurements and relative differences.

• Local accuracy is closely associated with relative values.
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**Types of Spatial Data**

- Absolute latitude/longitude/ellipsoid height.
- Relative lat/long/height - $\Delta \varphi/\Delta \lambda/\Delta h$.
- Absolute ECEF geocentric $X/Y/Z$ coordinates.
- Relative ECEF values, $\Delta X/\Delta Y/\Delta Z$.
- Absolute well defined (SPC) east/north/up.
- Relative SPC $\Delta e/\Delta n/\Delta u$. Is it true 3-D?
- Arbitrary $X/Y/Z$ values in an assumed system.

National Spatial Reference System (NSRS)

- [http://www.ngs.noaa.gov/INFO/OnePagers/NSRS.html](http://www.ngs.noaa.gov/INFO/OnePagers/NSRS.html)
  (The NGS establishes and maintains the NSRS.)
- NAD 27 – horizontal datum, outdated.
- NGVD 29 – vertical datum, outdated.
- NAD 83 – horizontal only, big improvement.
- NAD 83 (XXXX) – 3-D since (2007)
- NAVD 88 – vertical based upon geoid & 1 BM.
- WGS 84 – is both an ellipsoid and a datum.
- ITRF – defined and supported by scientists.
Models Used When Working with Spatial Data

• Local – assumed origin and orientation.
  - Can be horizontal or vertical (2-D or 1-D)
  - Or, it could be 3-D. What about flat Earth?
• State Plane Coordinates (and Elevation)
• Geodetic latitude/longitude/ellipsoid height
  - Geometrical geodesy, on ellipsoid surface.
  - Physical geodesy and geoid modeling.
• Geocentric ECEF, true rectangular 3-D. In this environment, elevation is derived. That’s OK.
Advantages of using State Plane Coordinates

- Used in many GIS data bases as absolute coordinates defining unique location.
- Computations use simple 2-D equations.
- One-way traverses are used instead of loops.
- Parallel grid meridians used in plane surveys.
- Elevations are added for third dimension.
- SPC have been standardized and accepted.
- Concepts integrated into commercial software.
Disadvantages of using State Plane Coordinates

• The map projection model is strictly 2-D.
• Distances are distorted in two ways:
  - Grid scale factor (projection 3-D to 2-D).
  - Elevation factor (horizontal not at sea level).
• Grid meridians do not portray true north.
• Elevations are used as third dimension but the reference surface for elevation is not flat.
• GIS needs unique designations. Many states have more than 1 zone. Texas has 5 zones.
Advantages of Using the GSDM

• All the pieces are in place & in public domain.
• Equally applicable world-wide, all disciplines.
• Provides a standard for data interchange.
• Model does not distort survey measurements.
• Supports use of spatial data accuracy.
• Preserves character of 3-D measurements.
• Inverse gives ground distance & true azimuth.
Disadvantages of Using the GSDM

- The concept is “new” and not widely used.
- Relies on understanding more than rote.
- Software options are, so far, limited.
- The GSDM supports too many options:
  - Geocentric Coordinates.
  - Geodetic coordinates.
  - State plane coordinates.
  - Local & assumed coordinates.
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**Spatial Data Accuracy**

- Digital spatial data are not “exact.”
- Consequences of bad data can be severe.
  - Mars probe crash $125 M – Sept. 1999


- Current spatial data accuracy standards:
- Stochastic model (of GSDM) handles standard deviations and error propagation.
Process and Content

• This part is abstract but worthy of discussion.
• Doing things right (process) and doing the right thing (content) are both important.
• Some equate:
  - Management with process and
  - Leadership and vision with content.
• See http://www.globalcogo.com/process.pdf
Conclusions - I

• Many persons use spatial data.
• Technicians can do an excellent job of collecting data/making measurements.
• Professionals solve problems by generating creative solutions – often using spatial data.
• Logic – what happens if I start with a simple assumption (a single origin for 3-D data) and add components defined by solid geometry? You get the GSDM!
Conclusions- II

• Spatial data accuracy is huge issue!
• How good are the data?
• What is the cost of good data?
• What are the consequences of bad data?
• Who is responsible for writing/enforcing the standards and specifications?
• The GSDM provides tools for establishing, tracking, and using standard deviations.
Additional sources of information

- Equipment vendors.
- Colleges and Universities.
- Other practicing professionals.
- Book – “The 3-D Global Spatial Data Model: Foundation of the Spatial Data Infrastructure”

Seminars - various
Additional Opportunities – SPAR 2011

• See http://sparllc.com/spar2011.php

• 3-D imaging and 3-D laser scanning for engineers, surveyors, photogrammetrists, etc.

• 11th Annual Meeting, March 21-24, 2011, Woodlands, (Houston) TX.

• On March 19th (at the same place) ASCE Geomatics Division will host workshop on:
  - The Global Spatial Data Model (GSDM) 4 hr.
  - Real-time GPS Networks (RTN) 4 hr.
  (Will qualify for continuing education credit.)