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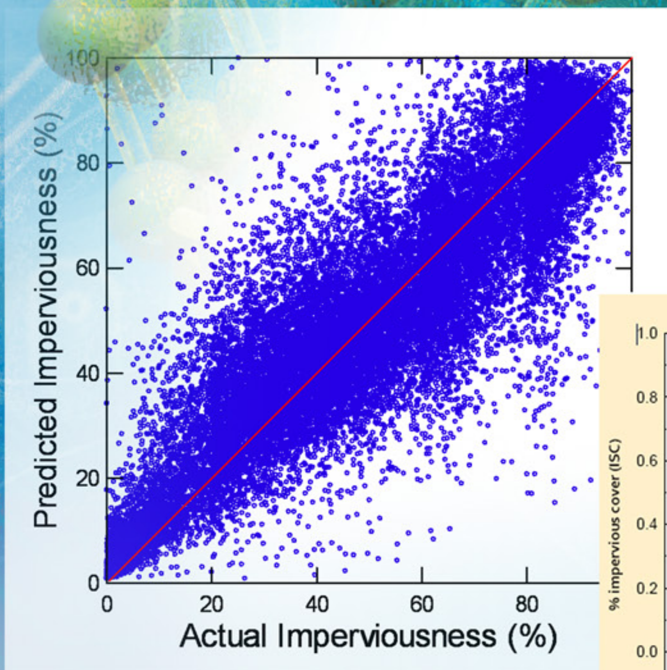

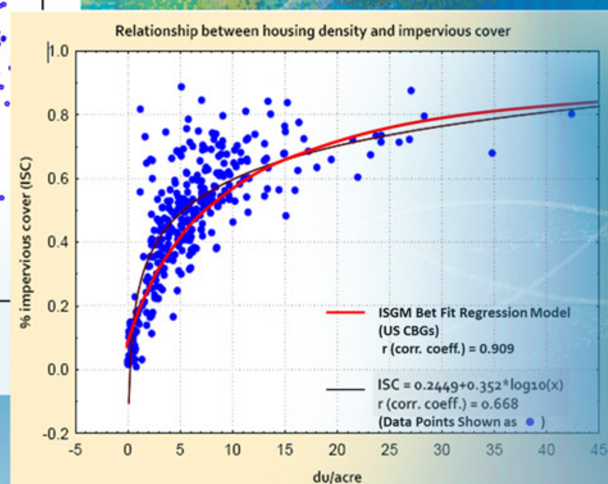

Papers of Practice, Technical Reports and Industry Notes

Improving Cadastre: Development of a Workflow Prototype Utilizing ESRI's Parcel Fabric

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Abstract: *The Rapid City/Pennington County, South Dakota, GIS Division has continuously maintained a parcel dataset that was originally created in 1989. Advances in technology and the desire to expand the use of land-based information, requiring highly accurate data, highlighted the need to improve the cadastre. Technical obstacles, such as incorporating and maintaining survey information as well as easily updating related layers, previously hindered this effort. The Environmental Systems Research Institute (ESRI) parcel fabric data model purports to have resolved many of these issues and was the focus of this project. A workflow was developed and an accuracy assessment performed during this study to test these claims. The project successfully addressed the following key factors: (1) conversion of the existing data, (2) maintaining and improving the integrity of the cadastre data over time, and (3) integrating these data with related data layers. Although the workflow was developed for Rapid City, it is scalable and it can be applied by any organization that maintains land records.*

INTRODUCTION

Efficient and effective management of limited resources, such as land, is becoming more and more important as the United States continues to grow and development densities compound. Rapid City, South Dakota, not unlike many other communities, uses geographic information systems (GIS) to manage its land records (cadastre[1]) and other spatial information. For example, its parcels dataset is used to maintain ownership and tax information, record zoning and other planning designations, track annexations, maintain corporate boundaries, and develop future land-use plans. To date, the cadastre parcels are a representation containing accurate attribute information about the land such as area, ownership, and tax value. Historically, there was no need for accurately surveyed spatial data because it was developed primarily for taxation purposes and little if any other relevant spatial data existed. However, in recent years, additional datasets such as high-quality aerial imagery and sanitary sewer infrastructure have been developed with high positional accuracy. These layers are constantly under consideration by engineering and planning staff, and when plotted with base layers, such as the parcels, disparities in accuracy between the datasets become apparent, thus highlighting the need to improve the accuracy of the cadastre layer. Two layers in particular are driving the city's interest in improving its parcel base: zoning and future land use. Having these layers available and up-to-date would increase staff efficiency when reviewing development submittals, improve customer service by having the data accessible to the public, and help expedite planning and engineering studies.

History of Cadastral Dataset of Rapid City

The original cadastral dataset for Rapid City was developed in 1989 (see Figure 1 for overview) from plats at three scales and adjusted to U.S. Geological Survey (USGS) 7.5 minute quadrangle section corners resulting in some errors. From 1989 through 2000, parcels were added by digitizing and using coordinate geometry (COGO) input methods. Rectified but not ortho-corrected aerial images also were used to help align the property lines. As new imagery was acquired, many lines had to be adjusted, especially in areas of high relief (Rapid City GIS Division 2009). In 2000, the parcels were converted to the Environmental Systems Research Institute (ESRI) ArcInfo Coverage format, and again some errors were introduced. According to the GIS Division staff, there was reasonably good conversion of the data in the eastern half of the county but less so in the western half (Rapid City GIS Division 2009). Not only were errors introduced during the conversion, but sometime after the project was finished, it also was discovered that the conversion vendor incorrectly moved section lines to match the digital line graph (DLG) section lines, rather than moving the parcels to the correct section. In addition, water boundaries were erroneously incorporated to represent parcel boundaries. In 2003, the ESRI ArcInfo parcel coverages were converted into one contiguous countywide ArcSDE feature class. Maintenance of the parcels has continued using ESRI's ArcMap desktop software by COGO input and other editing techniques.

From the original development of the parcels dataset through the conversions discussed above, errors have been introduced and continue to be propagated. Even the current methods used for

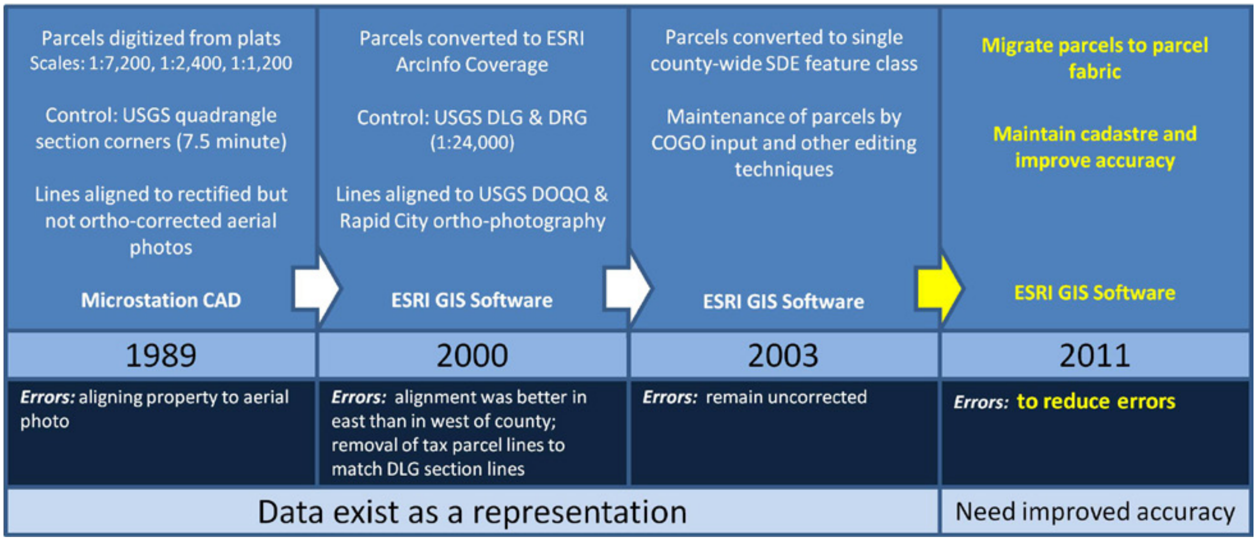

Figure 1. History of the creation and evolution of the dataset of the Rapid City parcels

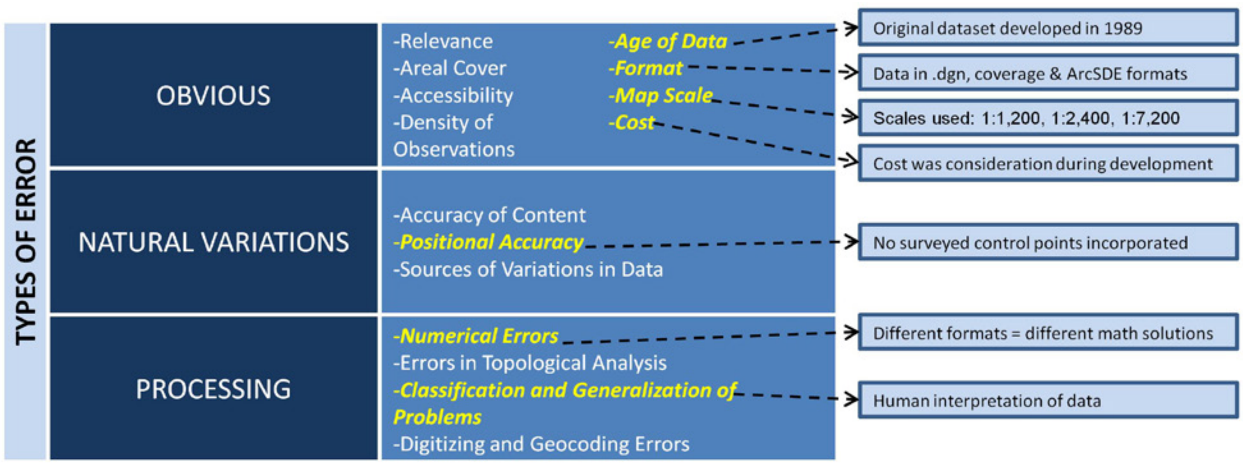

Figure 2. Sources of error commonly found in geospatial datasets (Foote and Huebner 1995) and how they apply to the dataset in this study

updating and maintaining the data introduce, if not maintain, error in the dataset. For example, when an area is newly subdivided, the surveyor of record's platted information is reproduced digitally using software with coordinate geometry (COGO) input capabilities. Data integrity then is often compromised so that the shape(s) can fit into the area available in the parcel layer instead of being truly represented.

Historically, one of the main factors limiting spatial accuracy in GIS systems was the capacity of hardware and software and their inability to handle geodetic coordinate systems effectively. However, as both of these have improved, this no longer is a limitation. The wide availability and substantial improvements in spatial data quality provided by global positioning systems (GPS), aerial photography, and other data-collection technologies have found spatial management and improved accuracy of cadastral databases struggling to keep pace (Harper 2006).

Although errors are naturally inherent in geospatial data, data collected by observation tends to suffer from imperfect quality more than other types of data as a result of subjective interpretation rather than precise measurement (Goodchild 1992). Foote and Huebner (1995) highlight three types of errors associated with geospatial data that are summarized in Figure 2. Several of these are present in Rapid City's cadastre (highlighted in yellow, Figure 2) and include obvious errors (age of data), natural variations (positional accuracy), and errors caused by processing of the data (numerical errors and geocoding and digitizing errors).

Once the sources of errors have been identified, making changes to the parcels dataset, whether to accommodate the dynamic nature of land configuration or make adjustments to improve accuracy, currently poses a problem. Handling other land-dependent layers, such as zoning, future land use, street centerlines, corporate limits, annexation boundaries, and utility features, becomes very resource-intensive if all changes being made to the land base are to be reflected in the associated layers.

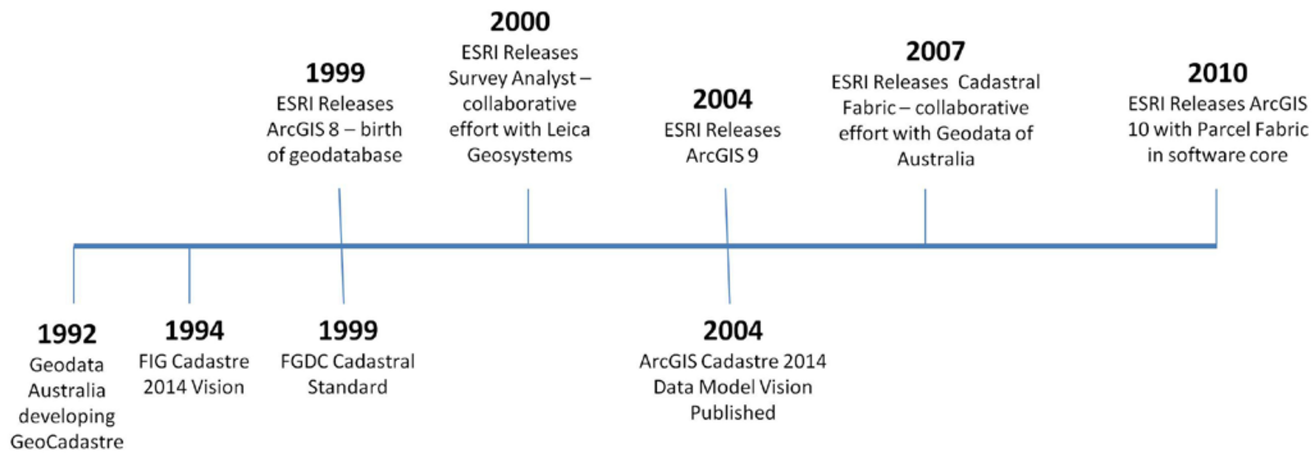

Figure 3. Generalized timeline of the introduction of cadastral standards, collaborations, and products

Historically, these changes have not been consistently maintained in the associated layers, producing a less than visually appealing result when the parcels are overlaid and troubling results when some spatial data analyses are performed.

Rapid City has several common cadastral objectives that include the development of cadastral layers with higher spatial accuracy, applying cadastral adjustments to associated layers, increasing accuracy over time by continuous updating and maintenance, and storing legacy data within the cadastre fabrics (Bhowmick et al. 2008). ESRI's parcel fabric data model appears to meet these objectives.

ESRI's cadastral solutions, including the parcel fabric data model, have been in development for quite some time and are the result of multiple collaborations. The data model was crafted to consider the objectives of the Cadastre 2014 Vision set forth by the International Federation of Surveyors (FIG) Commission 7 group and the Federal Geographic Data Committee (FGDC) Cadastral Data Content Standard for the National Spatial Data Infrastructure (Kaufmann and Steudler 1998, ESRI and Kaufmann 2004). Figure 3 is a generalized timeline of the introduction of cadastral standards, collaborations, and products leading up to the integration of the parcel fabric data model in ESRI's current software core.

In 2010, ESRI renamed cadastral fabric to parcel fabric, and changed the related tools and editing technology from an extension product to a part of the core ESRI software. The parcel fabric technology, which is the focus of this project, is the result of more than two decades of research and development by ESRI and its partner Geodata of Australia (Geodata 2006). Careful consideration given to national and international standards, decades of development, and the successful implementation of the GeoCadastre process in other countries (e.g., Australia, New Zealand (GeoData 2006); Vietnam (Huong 2010); United States (Florida: Capobianco and Mann 2009; Denver: Genzer and Tessar, 2011); see Konecny 2011 for overview of variation in land-management systems in diverse geographic regions) signifies that a potentially stable, comprehensive solution has been developed. ESRI committing to this model and incorporating this package into the standard GIS software provides further confidence that this is a model/framework that was developed with longevity in mind.

In essence, the model fits parcels into their appropriate locations in the fabric based on points the parcel has in common with the fabric. Once this has been accomplished, the fabric then can be associated with other layers, reducing discrepancies and mismatching of boundaries. Not only does the parcel fabric resolve the aforementioned issues, but it also allows for preservation of historical data (i.e., maintains records of previous transactions enabling the user to review the state of a chosen area over time) and the maintenance of data in multiple projections.

The ability to import existing data and improve it over time is very important to the city of Rapid City from a feasibility standpoint. Some have alluded that existing datasets should not be salvaged and continue to be improved upon, but rather the fabric should be built from scratch to ensure its integrity (Harper and Lee 2008). For a GIS Division with a full-time staff of three supporting both county and city GIS activities, it is simply not reasonable to use this approach. Rapid City's parcels dataset, which has been used largely as a representation, has served its original purpose. However, with the advancement of spatial data technologies and an increasing integration of digital data systems into daily workflows, the city and its stakeholders have expressed a desire to improve the accuracy of the parcels dataset and related base data layers. The remainder of this paper will outline and evaluate a workflow for preparing and importing existing data into the parcel fabric, adjusting the parcels to control points, performing an accuracy assessment of the adjustment, and applying the adjustments to an associated layer.

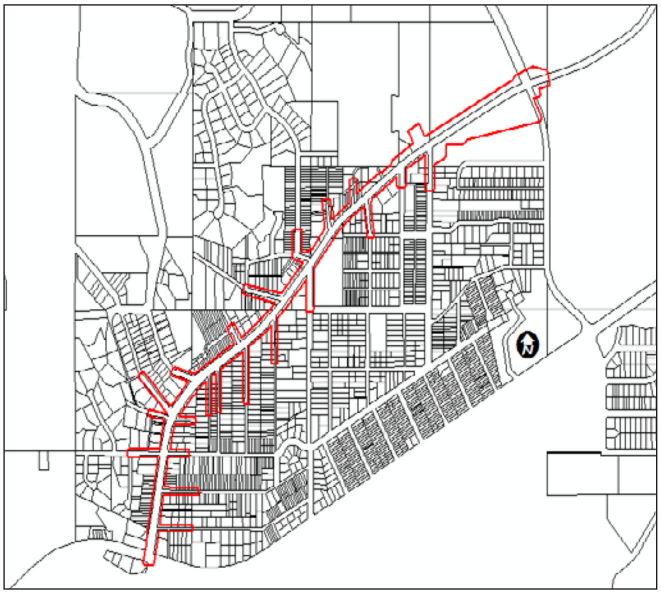

Figure 4. Map illustrating the cadastral data layer that will be used for this study. The Canyon Lake Drive neighborhood area contains approximately 675 parcels. The red line delineates the street reconstruction project zone and Canyon Lake Drive.

METHODOLOGY

Data

The data used for this study was a small portion of parcels from Rapid City's existing cadastre. The area was chosen because a major arterial street reconstruction project was recently completed in the area (see Figure 4), providing an ideal comparison dataset for use in this study. During the design phase of this street project, an accurate property layer had to be assembled so properties impacted by construction activities could be identified. Detailed property information also was necessary for developing construction easement documents and acquiring necessary rights-of-way. To develop the property layer, property corners in the project area were located and recorded using a mix of GPS and conventional surveying methods. Plats, easements, deeds, and other existing property documentation were retrieved from the county courthouse. A cadastral layer for the project area then was constructed in AutoCAD Civil 3D 2011, using the plats and surveyed property corner information. For this parcel fabric study, the surveyed property corners provided geodetic coordinates for import into the fabric to adjust the existing parcels to. And having the independently created cadastral layer provided an opportunity for a comparison to see how well the parcel fabric adjusted the parcels in the test area.

WORKFLOW

Five steps identifying the workflow necessary to test and implement the parcel fabric for Rapid City have been identified and are summarized in Table 1; they will be discussed in more detail in the following sections.

STEP 1	Building Framework
STEP 2	Preparing and Loading Data
STEP 3	Parcel Adjustment
STEP 4	Compare adjusted parcels to AutoCAD cadastre
STEP 5	Adjusting an associated layer

Table 1. Five-step workflow developed during this study

1.	LINES	Must Not Self-Overlap
2.	LINES	Must Not Self-Intersect
3.	LINES	Must Not Intersect or Touch Interior
4.	LINES	Must Be Covered by Boundary Of
5.	POLYGONS	Boundary Must be Covered By
6.	LINES	Must be Single Part

Table 2. Topology rules required at a minimum by the parcel loader to load data to the fabric

Step1: Building the Data Migration Framework

The first step in the workflow development of this project was reviewing existing documentation to identify the necessary steps required to prepare the data for loading into the parcel fabric. This included reviewing ESRI documentation and other available literature (which is limited for this is still a relatively new component) as well as conversing with ESRI personnel. The workflow step developed consisted of approximately 12 items. This includes technical and data-related tasks such as verifying software version, installing necessary components such as the Curves and Lines tool (ESRI 2010), creating workspaces, and verifying projection and coordinate system information. Feedback in the form of verbal communication was received from the end user and incorporated into the final workflow procedure.

Step 2: Preparing and Loading Data to the Parcel Fabric

The second step required preparing and loading data into the parcel fabric and documenting the steps involved. Using the rules required by the parcel fabric (see Table 2), a topology of the lots was created and successfully verified.

However, the parcel loader failed to load the lot lines, citing topology errors. Further investigation revealed that even though the data passed all the topology requirements, additional editing of the data was needed. This included using tools to planarize the lines (i.e., break at intersections (Figure 5A)) and split multisegment lines at inflection points (Figure 5B) (i.e., where a curve transitions into another curve, or at sharp bends, etc. (ESRI 2010)).

Tax parcels were loaded next. Assuming that the same approach the city had been using for deriving tax parcels (dissolv-

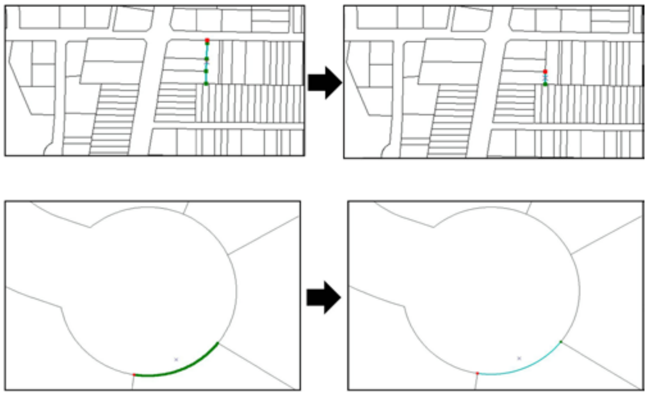

Figure 5. Examples of topology errors prior to (A) planarizing and (B) conversion of lines to two-point curves

Figure 6. Control points loaded into the fabric for the study area and associated with the appropriate parcel corners

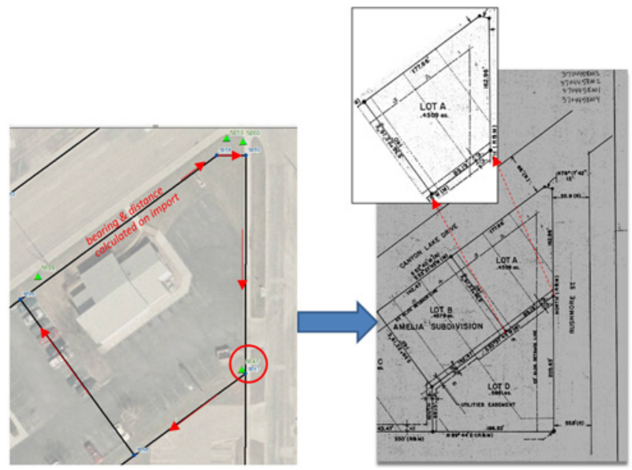

Figure 7. A parcel in the parcel fabric resulting from the import of existing data (left) and an image of its corresponding plat (right)

ing by attribute) would be appropriate, tax parcels were derived from the lot lines that had been successfully loaded to the fabric. Again, a topology was created and verified and the tax parcels were loaded. The parcels were within the tolerances required by the parcel loader and loaded without error. However, on close visual inspection, the tax parcel lines were not coincident with the lot lines loaded previously. Apparently, the process of dissolving the features by attribute resulted in a slight amount of movement. The concern with the movement is mostly cosmetic in nature, for it did meet the tolerances required by the parcel fabric. However, Rapid City did choose to pursue another option that would result in coincident lines, as described next.

To address this issue, tax parcels were re-created from the lot lines. Two different approaches can be used to isolate the lot lines that need to be removed to derive the tax parcels. The first option is to simply order the layers in the *Table of Contents* of the project so that the tax parcels are on top of the lot lines and visually select all the lot lines that are not parcel boundaries and delete them. The other option, and one that will be more practical for Rapid City to use on the countywide dataset, is to use select by location with *Target layer(s) features are within (Clementini) the Source layer feature* option selected. This should result in most of the lot lines that are not tax parcel boundaries being selected, which can be deleted at the same time. However, if this method is used, it is important to check for lines that may have been erroneously removed. Two methods can be used here and include (1) by visually inspecting the layers and (2) comparing polygon counts with the original tax parcel layer.

Once the tax parcel lines and polygons were successfully loaded to the fabric (and checked), the control points were loaded to the fabric. Associations were made between the parcel corners and corresponding control points (see step 3 for more detail) (Figure 6).

Control points define accurate, surveyed x,y,z coordinates for physical features on the surface of the earth and in this study consisted of property corner monuments that had been located on the ground and coordinates recorded. While parcel dimensions accurately define parcel boundaries in relation to each other, control points, when used in a least-squares adjustment, result in accurately defined spatial locations for parcel corner points (ESRI 2011), See step 3 for more details.

To summarize step 2: The existing parcels dataset consisted of parcel shapes without any coordinate geometry (COGO) attributes (i.e., bearing and distance of record) and did not necessarily truly represent the shape of the parcel (too many vertices and line segments making up the curves); it was processed and imported into the parcel fabric. The data-processing component of this workflow step consisted of breaking down these shapes into components that closely represent the platted shapes (see Figure 7) (i.e., two-point lines and parametric curves) and was accomplished through planarizing the lines and identifying the curves. The result was a fabric-ready set of lines, points, and polygons. The more closely each parcel represents its originally platted course, less editing and maintenance will likely be required once the data has been loaded to the parcel fabric (Denver GIS 2011).

Step 3: Adjusting Parcels to Control Points

As previously mentioned, the third step in the process is to use the least-squares adjustment built into the parcel fabric to adjust the existing parcels to surveyed control points. During this process, control point coordinate values are held fixed while the horizontal

Figure 8. An example of an area of parcels that is well balanced geometrically with evenly distributed control

and vertical coordinate system of the control points is transferred to the parcel fabric. In other words, control points are processed together with recorded dimensions to derive new, more accurate coordinates for parcel corners (ESRI 2011). Line dimensions (attributes representing the original survey) are not changed, but fabric point coordinates are updated and the geometric and spatial representation or the parcel line shape is updated. The result is an accurate coordinate-based cadastral system.

Least-squares adjustments are one of the most rigorous yet easy to apply without bias adjustments and are defined by Craig and Wahl (2003, p. 92) as being "based on the mathematical theory of probability and the condition that the sum of the squares of the errors times their respective weights is minimized." They also point out that one of the most important benefits of using the least-squares method of adjusting is that all types of survey measurements can be analyzed simultaneously.

In the parcel fabric, this adjustment is applied to a group of selected parcels and should be in an area that has a reasonably well-balanced geometric shape with redundant measurements (i.e., where multiple observations are made of the same point) and evenly distributed control (Figure 8).

Repeated observations validate a measurement network and a parcel fabric is a redundant measurement network. As pointed out by Craig and Wahl (2003, p.92), "Prudent surveyors check the magnitude of the error of their work by making redundant measurements."

Each parcel dimension and thus each parcel in the parcel fabric can have an associated accuracy. This is because parcel dimensions are derived from raw survey measurements, which have associated accuracies. By default, accuracy in the parcel fabric is defined by survey date because, in general, surveying equipment is more precise today than it was in the past, allowing for relatively greater accuracy in survey representations of parcel corners (ESRI 2011).

Accuracy assignments in the parcel fabric are important in the least-squares adjustment because parcels with a higher accuracy assigned to them will have a higher weight in the adjustment and will adjust less than those parcels with lower accuracies. In other words, low-accuracy parcels will adjust around the more accurate parcels (ESRI 2011). ESRI uses seven accuracy levels with the highest level of accuracy given to the most recent surveyed data, mainly because of the ability for modern survey equipment and procedures to more accurately capture parcel data.

Data that were imported in previous steps of the workflow were automatically assigned an accuracy level of six, the lowest that can participate in an adjustment for the dimensions were calculated on import and not entered from a plat. If the data had been entered off a plat, then an accuracy level could have been assigned based on the date of the plat and would have ranged in accuracy between 5 ppm and 1,000 ppm.

Prior to running a least-squares adjustment, ESRI recommends checking the fit of control points. This calculates the transformation between the linked fabric point coordinates and the coordinates of the control points. The calculated parameters then are applied to the linked fabric point coordinates to compute temporary new values for the fabric point coordinates. The difference between the newly calculated fabric point values and the original control point values are reported as residuals for each active control point. Large residual values can indicate a problem in the data and should be investigated further. For instance, a large discrepancy (identified as being outside the range of the rest) may be the result of a poor control point, inaccuracy in the parcel data, or control points incorrectly matched to corresponding parcel points, and should be further investigated prior to applying the adjustment.

Perhaps one of the biggest drawbacks of the least-squares adjustment is that one wrong piece of information that goes undetected can greatly distort the results of the adjustment. This is because in the squaring process large residuals are dominant. A large measurement error that is ten times larger than the others will have the same effect on the sum of the squares as will 100 of the others (Craig and Wahl 2003). However, the dominant effect of squaring large residuals also enhances the ability to identify large errors that do not fit with the rest of the data and thus allows easier detection of mistakes that need to be removed or corrected. Therefore, it is imperative that the statistics be reviewed and suspect residual values addressed prior to committing an adjustment.

Step 4: Accuracy Assessment

The fourth step in the workflow is to perform an accuracy assessment of the adjusted data. In this case, an AutoCAD layer that was independently constructed from original plat documents and surveyed control points was used to make comparisons. Plotting the parcel fabric with the AutoCAD layer and visually inspecting how the two overlap was the first assessment of how well the adjustment performed. In areas where there is no independent work to check against, a visual inspection against aerial photography or other such imagery will provide some verification of the success of the adjustment. However, visual inspection of the data is

Table 3. Summary of ranking system used to evaluate success of least-squares adjustment

Rank	Percentage of Parcel Lines +/- 2.0 feet from Control Layer
1	100 – 90%
2	89 – 75%
3	74 – 50%
4	49 – 0%

a qualitative assessment; therefore, a more quantitative approach also was used. Twelve samples were taken with a range of seven to 44 parcels in size. Each sample was adjusted, using the least-squares method described above. Accuracy of fit was performed visually by viewing how well the parcel boundaries overlapped, analyzing the output statistics provided by the software, as well as ranking accuracy based on what percentage of the parcel lines were within +/- two feet of the control layer boundaries as described in Table 3. The percentage of parcel lines within +/- two feet of the control layer was determined by buffering the control layer lines and performing a spatial query.

Standards, such as the U.S. Geological Survey (USGS) National Map Accuracy Standards (NMAS)[2], were reviewed when considering an appropriate tolerance for evaluating the accuracy of parcel fabric adjustments. However, as pointed out by the International Association of Assessing Officers (IAAO), "The NMAS is most appropriate for paper maps which are only viewed at a printed scale,"[3] and also contends that "no one accuracy standard meets all needs" because of the differences between urban and rural environments (IAAO 2009, p. 10).

For this study, it was understood that the cadastral data will not be published at a static scale, the area under consideration is urban in nature, and Rapid City has obtained highly accurate utility location information that is helping drive the desire to improve related cadastral information. Knowing this, an accuracy range of +/- two feet was selected for evaluating parcel fabric adjustments for this project and was based partially on tolerances that were established by a parcel fabric project implemented by a utility company (Colorado Springs Utilities), whose cadastral products also are consumed by local government agencies (Moran et al. 2008). In summary, for the purpose of this study, accuracy was assessed using the ranking system summarized in Table 3.

An initial assessment of the 12 samples found that only 8.33 percent of the samples were fitting well (ranked 1 or 2) prior to any adjustments being applied. After the first adjustment was performed, this only increased to 25 percent of the samples. The reasons for this may be the result of a number of problems that include: incorrect shape of the parcel boundaries; inaccurate control points; inadequate control points; disproportionately distributed control points (i.e., larger number of control points on the perimeter of the sample and/or clustering of control points with large gaps between control points).

(a) **Incorrect shape of the parcel:** If the shape of the parcel is incorrect, then the shape will need to be re-created using the original plat document and rejoined to the fabric. Obviously knowing this is difficult without a dataset for comparison, as has been done during this study. When the northing and easting values are not converging to zero or stabilizing during the adjustment, this can indicate incorrect shape. Therefore, visual inspection against a control layer (as was done in this study) or aerial imagery can be used.

(b) **Inaccurate control points:** If a control point is problematic, it will need to be either corrected or deactivated and the adjustment reapplied. High or irregular residuals during the check fit indicate an inaccurate or incorrectly associated control point.

(c) **Inadequate control points:** There may be instances where there are few if any control points in an area that correction is desired. If there are none, obviously some will need to be acquired. If there are too few to perform the adjustment, or the points available are clustered, some additional points should be obtained to strengthen the adjustment.

(d) **Distribution of control points:** For cases where the distribution of control points is poor, additional control points will need to be added before applying an adjustment. Distribution of control points causing an adjustment to perform poorly can be identified by ruling out problems addressed in points (a) and (b) above. If neither control point accuracy nor shape appears to be an issue, then distribution of control points should be evaluated. If there are more control points around the outer edge of an adjustment area than inside, and the adjustment performed well around the outer boundary but not well internally, then it is reasonable to pursue adding some additional control points inside the adjustment area.

To identify what issues might be inhibiting the potential of the parcel fabric adjustment, each sample area was evaluated starting with the lowest ranking sample. Going through each of the steps listed above, a visual inspection was performed comparing the parcel shapes in the sample area to the control layer, assessing the reasonableness of the control point accuracy, and looking at the number and distribution of the control points. Notes were taken regarding what was observed and appropriate action taken (e.g., adding additional control points, inactivating bad control points, improving distribution of control points by adding more, etc.). In areas where the distribution of control points was obviously skewed (e.g., all control points located around the outer edges), an attempt was made to disperse the added points in as balanced a manner as possible.

Step 5: Adjusting an Associated Layer: Zoning

The fifth step in the workflow process is to apply the parcel adjustment to an associated layer. For this study, the zoning layer was chosen. If the desire is to adjust a parcel-based layer, such as zoning, it must be associated to the parcel layer being adjusted before the adjustments are performed. As such, the first step of this workflow was to verify that the zoning layer was associated with the parcels. After the parcels were adjusted, the adjustment vectors then were applied to the zoning layer, resulting in the zoning layer now aligning with the parcels that were adjusted (sample 7, Table 4) and thus moved during this process (Figure 9). Seeing this happen successfully was a big victory because one of the biggest challenges the city faced adjusting parcels in the past was how to efficiently and accurately apply these improvements to related layers.

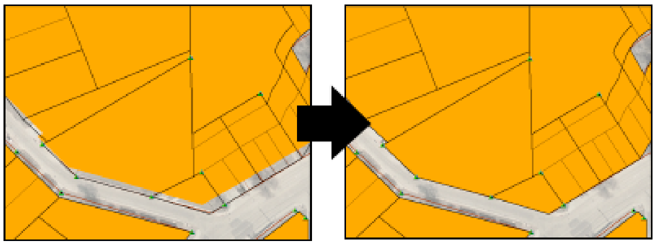

Figure 9. Zoning (shown in orange) prior to (left) and after (right) the parcel adjustment vectors were applied

RESULTS

The development of the workflow described in this paper has been an interactive and iterative process with Rapid City to ensure that the process can be executed successfully and applied to the remaining parcels for Rapid City and Pennington County (approximately 40,000 parcels). At the conclusion of each step, a written workflow process has been provided. All workflow steps have been tested by at least one staff member of the GIS Division for usability and feedback has been incorporated in the final workflow.

Based on the material presented in this paper and feedback received from the city of Rapid City GIS Division, the workflow that was developed as a result of this study has successfully met the objectives that were set forth for the project and included (1) developing a feasible workflow for converting existing data; (2) maintaining and improving the integrity of cadastre data over time; and (3) being able to integrate these data with related layers.

Accuracy of the parcels was greatly improved using a multi-step reiterative adjustment procedure as outlined in the methodology. During this study, two adjustments were required to reduce inaccuracies and are summarized in Table 4 below.

When the data was first loaded into the parcel fabric (step 2) and compared with the AutoCad layer, only one sample (8.33 percent) was ranked 1 (i.e., containing > 90 percent of the parcel lines within +/- two feet of the lines in the control layer (Table 4)) and ten samples (83 percent) ranked 4 (i.e., < 50 percent of the parcel lines being within +/- two feet of the control layer lines (Table 4)). After applying the least-squares adjustment (see first adjustment, Table 4), the number of parcel lines that were within +/- two feet was somewhat improved. The number of parcels ranked 4 was reduced from 83 percent to 16 percent, 50 percent of the samples were ranked 3, and 25 percent were ranked 2 (Table 4). After evaluating each sample for adjustment performance and addressing any deficiencies or inaccuracies (see Table 5), a second adjustment was applied, resulting in 75 percent (9 out of 12 samples) achieving greater than 75 percent of the parcel lines falling within +/- two feet of the control layer lines.

Of the 12 samples that were adjusted, one sample (sample 3)

Table 4. Summary of the quality of the parcels prior to applying any adjustment, after the first adjustment was applied and again after revisions were made for each sample and a second adjustment was applied

Sample	Rank % Match Preadjust.	Rank % Match after 1st Adjust.	Rank % Match after 2nd Adjust.	Problem of Accuracy	Fix
1	4	3	1	Inadequate control (c)	Points added: 4
2	4	3	2	Disproportionate control (d), inadequate control (c)	Points added: 3
3	4	4	4	Bad parcel shapes (a)	Needs to be redigitized from plat
4	4	2	1	Disproportionate control (d), inadequate control (c)	Points added: 6
5	4	3	1	Disproportionate control (d), inadequate control (c)	Points added: 3
6	4	4	3	Disproportionate control (d), inadequate control (c)	Points added: 5
7	3	2	2	Disproportionate control (d), inadequate control (c)	Points added: 1
8	4	3	1	Disproportionate control (d), inadequate control (c), bad control (b)	Points deactivated: 1 points added: 2
9	1	1	1	No problem	
10	4	3	3	Disproportionate control (d), inadequate control (c)	Points added: 6
11	4	2	2	Disproportionate control (d), inadequate control (c)	Points added: 6
12	4	3	2	Disproportionate control (d), inadequate control (c)	Points added: 5

Table 5. Adjustment statistics for sample 3 and sample 9

Description	Sample 3	Sample 9
# Control Points	10	14
# Parcels	26	21
# Points	54	37
# Bearings	176	140
# Distances	176	140
# Unknowns	114	67
Redundancy	238	213
Bearings > Tolerance	3	0
Distances > Tolerance	9	0
Close Points Found	0	0
Line Points Found	0	0
Max. Easting Shift	-17.206	-9.885
Max. Northing Shift	-25.805 (745)	-10.016 (1060)
Avg. Easting Shift	0.123	-1.253
Avg. Northing Shift	-1.527	-0.051
Avg. of Coordinate Residuals	1.24	0.77
Std. Deviation Coordinate Residuals	7.77	4.51
Adjustment Rank	4	1
Comments	Did not converge or stabilize. Failed after 4 iterations.	
Number of Control Points	10	14
Number of Control Points Inside	1	4
Number of Control Points Outside	10	10
Lines within 2 Feet of Control Layer	14	35
Total Number of Lines	60	36
Percent Match	23.33	97.22

Figure 10. Images of sample 3 (lowest ranking) and sample 9 (highest ranking) before and after adjustment was applied

showed no improvement; four samples (1, 4, 5, and 8) improved from rank 4 to rank 1 (> 90 percent of lines within +/- two feet); two samples improved marginally (rank 4 to 3 (50 percent to 74 percent of lines within two feet)); and the remaining samples improved to within 75 percent to 89 percent of lines within +/- two feet. The reasons for these improvements and lack of improvement (e.g., sample 3) are summarized in Table 4. Overall improvements were possible by adding between one and six control points.

The lowest ranking area was sample 3 and the highest ranking area sample 9 (Figure 10 and Table 5). Sample 3's performance is the result of a bad shape. This is evidenced by comparing the parcels to the control layer, the adjustment solution not converging to zero, and by the high maximum northing shift in the adjustment statistics. To improve this area, the parcels should be re-input from the original plats, joined to the fabric, and readjusted. No matter how many times a least-squares adjustment is performed, if the shape being adjusted is not at least representative of the space available, it will never reach an ideal solution.

A significant amount of improvement was made in the sample areas adjusted by adding additional control points and ensuring that they were well distributed inside of and around the boundary of the area being adjusted.

CONCLUSIONS

The parcel fabric data model provides a comprehensive way to manage cadastral information that can maintain historical parcel information in conjunction with detailed, survey information including geodetic coordinates. Once the cadastre has been created, it also can be continuously improved over time and efficiently associated with parcel-based layers, as illustrated by the successful achievement of the objectives set forth in this study. These include (1) developing a feasible workflow for converting existing data; (2) maintaining and improving the integrity of cadastre data over time; and (3) being able to integrate these data with related layers. This data model has provided Rapid City with the ability to improve its digital cadastre with a limited amount of resources. Understanding that care should be used when adjusting data of unknown or poor quality, it has been suggested to Rapid City that as long as the adjustments being made are checked against information of known good quality, this is a reasonable way to move forward and improve the quality of the existing data.

Land records information has historically been stored in GIS databases by individual components: points, lines, and polygons. One distinct weakness of this data model has been its inability to associate line and point features to the polygons they represented. There was also no efficient process or method that allowed for new improved data to be incorporated, making it difficult to update property-dependent layers. In addition, distributing error for plat misclosures (Bunten 2008) also was challenging. The parcel fabric data model has addressed these shortcomings, resulting in a living land records system that is robust and more efficient to maintain and update.

Not only is it important to have a digital parcel dataset for assessing and collecting taxes and tracking land ownership, it also is becoming increasingly necessary that the accuracy and accessibility of land records information be improved for better resource management (Folger 2009), national security (Enemark 2010), critical infrastructure (Harper 2006), and emergency response efforts (Binge 2010). As pointed out by Brown and Moyer (1989), land is one of the most fundamental resources and, historically, records of this resource have been poor. However, as growth and development continue to occur, restricting the availability and challenging the resilience of this resource, having up-to-date and accurate information will be critical for the decision-making process. Craig and Wahl (2003, p. 95) contend that by having accurate spatial representations of land in a GIS, "the decisions about the locations of improvements and resources on the land will not be subject to costly errors and assumptions." One example of a community striving to improve the management of its land resources by developing a seamless parcel dataset is highlighted by Bunten (2008). The city of Duluth, Minnesota, embarked on a five-year project to "actively try to better manage development, its infrastructure and protect the natural environment, including the Lake Superior watershed" (Bunten 2008). This project was undertaken prior to the introduction of the parcel fabric data model and some of the challenges of working with land records information as individual components (points, lines, and polygons), as highlighted above, were encountered. The workflow developed during this study could easily be applied by a municipal organization, such as the city of Duluth.

The findings in this study reveal that one of the biggest challenges in migrating to the parcel fabric is preparing and loading existing data. The workflow developed during this study provides a means for systematically finding and addressing some of these pitfalls, which will result in more efficient implementations. The accuracy assessment presented in this study also provides users with a means for identifying problems when applying adjustments in the parcel fabric and outlines steps that can be taken to correct these issues.

For several decades, there have been voices defending the need for a nationwide cadastre in the United States (Foster 2008). While this has not been achieved to date, there have been successful statewide cadastres built, which is a step toward the goal of developing a national seamless parcel database. One such example is the state of Montana where the average annual benefit of having accurate accessible land records information is in the million-dollar range (Zimmer 2007). This example highlights the cost savings and efficiency realized by having an accurate, seamless dataset of land records. Countrywide digital seamless cadastral coverages of survey-grade accuracy also have been successfully developed. One such example is in New Zealand. Land Information New Zealand (LINZ) is an online seamless parcel data system that provides government officials, surveyors, and the public with more than 150 years of titles, survey marks, plans, etc., resulting in a significant increase in efficiencies for title research, land transfers, and filing of certified documents by surveyors. LINZ is supported by the New Zealand Institute of Surveyors and New Zealand Law Society (Richardson 2008). As more organizations adopt a common data model for storing land information, such as the parcel fabric, the effort of moving the United States toward a National Cadastral Dataset, as provided for in the National Spatial Data Infrastructure, will be strengthened.

Historically, surveyors have been remote from the GIS industry because GIS cadastral coverages were not representative of the precisions maintained by surveyors (Harper and Lee 2008). However, limitations in hardware and software that existed previously have largely been overcome. "Survey accuracy in a cadastral database encourages a mutually beneficial environment for both surveyors and GIS professionals" (Harper and Lee 2008). The development of a national parcel database would provide an opening for surveyors to be leaders in geospatial technology by viewing their work as a societal resource rather than a proprietary asset (Jones 2010).

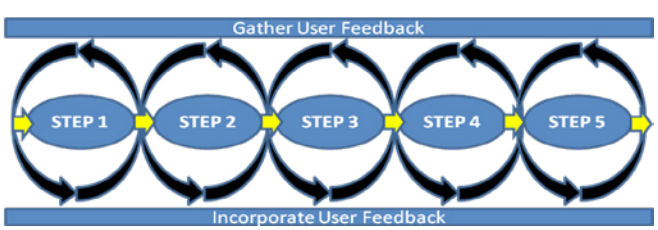

Figure 11. Interactive and iterative process used for testing workflow usability

FUTURE WORK AND RECOMMENDATIONS

The workflow that was developed during this study was an iterative process that included significant involvement from the end user (Figure 11) at each step, resulting in a process that can be implemented immediately. In fact, the workflow developed here currently is being used by the city of Rapid City to convert existing cadastral data to the parcel fabric. Because the workflow is generalized and quite scalable, it can be implemented elsewhere with other datasets for the principle requirements are the same (i.e., develop a framework (step 1); prepare the data (step 2); adjustment of the data (step 3); quality checking through accuracy assessment (step 4); and adjustment of associated layer(s) (step5)). The workflow can be adopted by both large and small organizations managing land-records information in both the public and private sectors. The applicability of this workflow is further supported by the response received at the GIS in the Rockies Conference 2011, where this work was presented. Representatives from a variety of sectors, including local governments, utility companies, the software vendor (ESRI), and private corporations, all expressed interest in the workflow that was developed.

Even though the workflow created during this study can be widely applied, the next logical progression of work to be conducted on this project is developing a subsequent workflow for Rapid City to identify specific processes for handling daily tasks once the legacy data has been migrated to the parcel fabric. Some of these include integration of new land transactions into the fabric, adjusting parcels to control points, incorporating newly acquired control points, refining cartographic elements (e.g., dimension annotation, parcel labels, etc.), and publishing the parcels dataset via a Web-mapping interface for end-user consumption.

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Notes

[1]An individual parcel of land on which the identification of land rights resides (Enemark 2010) and an official register of the value and ownership of a parcel of land used in assigning taxes (Robillard et al. 2011).

[2]The NMAS states that "for maps on publication scales larger than 1:20,000, not more than ten percent of the points tested shall be in error by more than 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, 1/50 inch" (USGS 1947).

[3]A standard publication scale for cadastral mapping is in the 1:1000–1:1200 range (FIG 2009; Kennedy and Ritchie 1982), translating to an accuracy of 90 percent of all measureable points/lines falling within +/- 3 feet to +/- 3.33 feet (Foote and Huebner 1995) and tested by comparing to corresponding positions as determined by surveys of higher accuracy (USGS 1947).

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