Maintaining Spatial Relativity of Utilities after DCDB Upgrade

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ABSTRACT

The Surveyor-General's Department is responsible for the ongoing development and maintenance of the Digital Cadastre Database (DCDB) in New South Wales. As such they have the onerous job of improving the accuracy of the DCDB to meet the requirements of other users.

When the DCDB is moved to be more representative of the real world, spatially dependent datasets are no longer located in their correct relative position. Utility Companies and Local Government typically hold spatially dependant datasets. These organizations receive updated DCDB containing new subdivisions and compilations, and therefore have to adopt the new DCDB. They then have to identify areas in the new DCDB which have been upgraded, and upgrade their data to fit the new DCDB.

This paper sets the case for the use of the Least Squares "Parametric Variation of Coordinates" technique, and how this theory has been implemented in the Spatial Adjustment Engine to carry out a Utility Upgrade after the DCDB has been upgraded.

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INTRODUCTION

Many Utility and Local Government organizations have elected to locate their asset data for drainage, sewerage and cables, relative to the Digital Cadastral Database (DCDB). Various placement rules have been used to derive coordinates for these assets. However, these rules are not usually stored with the data. For example, it is very common for electricity, gas, water and sewerage to be placed at standard offsets from street frontages. Electricity may be at 2.0m from the boundary, whereas, sewerage lines are set to 0.3m from the boundary to avoid the issue of maintenance bills when the pipe breaks inside the private property.

Other rules may also exist. Any one span of overhead power cables must be considered to be a straight line due to the physical laws relating to the tension in overhead cables.

The DCDB was itself digitized from various map sources. The accuracy of the DCDB is therefore dependent on the accuracy of the original map, and the skill of the digitizer operator. If 1:25,000 mapping was used, the accuracy of the DCDB is probably around 25 metres. However, in some cases through good digitizing practices, the DCDB looks much better than this. For example long straight lines appear straight, right angles are near square, and parcel dimensions appear close to being correct. Nevertheless it is most likely that the DCDB will be updated and upgraded at some point in time. When the DCDB Custodian upgrades the DCDB to make it more representative of reality, it is common for the correct relative location of the assets in a spatial database to be lost.

This paper explores the geometrical relationships of this spatial problem, and explains how the "Spatial Adjustment Engine" uses the Least Squares "Parametric Variation of Coordinates Technique", which re-aligns the correct relative locations of asset data to the newly upgraded DCDB, to carry out Utility Upgrades.

MAPPING the PARAMETRIC ADJUSTMENT APPROACH to UTILITY UPGRADES

This adjustment technique was developed to deal with observation errors in control surveys carried out by Surveyors. It is based on the principle that every angle (2 directions) and distance has some small but statistically predictable error in it. Each of these errors combines to form the traverse misclose, which must be eliminated, or minimised to obtain the most likely coordinates for each point in the traverse. In other words, the Parametric Adjustment approach allows the shape of the traverse to be changed by the least amount, taking due consideration of the relative accuracy of all the measurements, but meeting the requirement of fitting certain key control points.

Moving this technique to Digitized Data is a small conceptual leap. Instead of using directions and distances measured by the surveyor in the field, the directions and distances derived from the digitized coordinates are used as measurements.

In the field survey, the object of the control survey adjustment is to fit measurements between certain traverse points to their equivalent Control Points, i.e. the traverse point adopts the coordinates of the State Survey Mark. These Control Points are often considered fixed, and are not allowed to move in the adjustment process.

In the Utility Upgrade scenario, the situation is fundamentally the same, and only a little more complicated. The surveyor's field traverse is equivalent to the combination of the linework from the utility theme and the original cadastre. Certain points in this 'made up' traverse are mapped matched to their equivalent points in the new cadastre. The new cadastre, which is treated as containing the Control Points, is not allowed to move in the adjustment process. It has to be adopted to fit other datasets that are held by the DCDB Custodian and other organizations.

Once this process has been carried out, the beginnings of an adjustment can be built. The directions and distances can be derived from the old cadastre and the asset layers, and the points in the old cadastre are substituted with their equivalent points in the new cadastre.

The one thing missing is connections between the old cadastre and the asset layers. Almost without exception, the assets are not located on the boundary of any parcel in the DCDB. Without these connections, the old cadastre would move to the new cadastre, but the asset layers would not follow as there are no connecting directions and distances joining the two.

TOPOLOGICAL PROBLEMS IN UTILITY UPGRADES

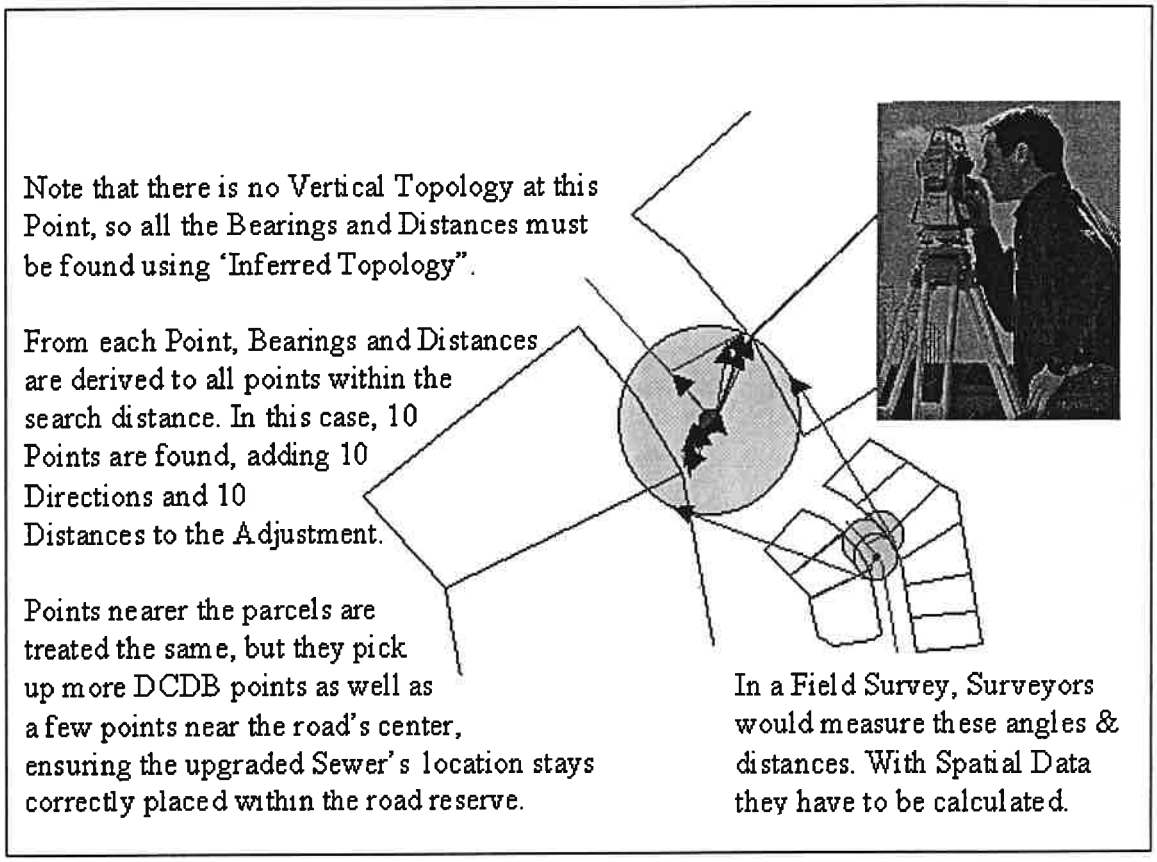
Upgrading Utility Layers is more complex than just applying shifts derived from nearby points in the cadastre. The following section will explore some of the more complicated geometrical problems that need to be addressed to deal with this problem more fully.

Inferred Topology

Because the relative location of assets with respect to the DCDB is not explicitly stored, topological relationships must be derived from the existing database. These derived relationships are therefore referred to as "Inferred Topology". For example, there is an 'inference' that an asset located at the half angle of a bend in the cadastre, and at a certain offset, should be at that position after the shift to the new cadastre.

It is relevant to introduce an Inferred Topology Search Distance at this point. This Search Distance defines which spatial objects in the database have inferred topology with other objects. If this distance is too short then no inferred topology will be formed, which in turn will cause the asset data to be "left behind" in the adjustment.

Setting this distance too large will mean the shifts on the asset will be partially based on points that are not nearby. For example, an extreme case would be to set this distance at 200 metres in an urban situation. This would mean that the asset's new location would be affected by shifts in the back boundary of surrounding parcels, which had no relevance to the position of an asset when it was originally placed.



Each point in each polyline and polygon theme is connected to one or more points. The topology at a point can be thought of as a list of points to which a straight line is drawn. In the case of cadastre, when all of these lines are drawn, every parcel is drawn, and in the case of the sewerage layer, all of these lines show the sewerage pipes.

The Inferred Topology of a point can be expressed as a list of points in the same way. The difference is that the lines are drawn between different themes, in this case the old cadastre and the asset data

These lists of coordinates are converted to directions (angles) and distances, which is the input data to the adjustment process.

Once these are obtained, all that is required is to run a parametric adjustment, using the "Variation of Coordinates" technique. The Spatial Adjustment Engine, Havoc, and other adjustment programs are built to take this type of observational input. If the same weighting is used for each observation, they will produce the same results.

SOPHISTICATION LEVEL 1

At this level of sophistication, it is useful to explore the likely results one could obtain from the adjustment.

Assets located near boundary points would be moved to their correct location, as half angles and half angle distances would be substantially preserved. Points located near the middle of the road would be proportioned to the new position, based on changing road widths. Georeferencing errors present in the original digitizing process would be fixed, as the new cadastre would address these issues. This refers to errors in registering the map against known points when the plan was originally digitised. These errors are typically small, and measure the shift in Easting and Northing, and the rotation and scaling of the map's positioning during digitizing against the real world coordinates.

ACHIEVING A BETTER RESULT

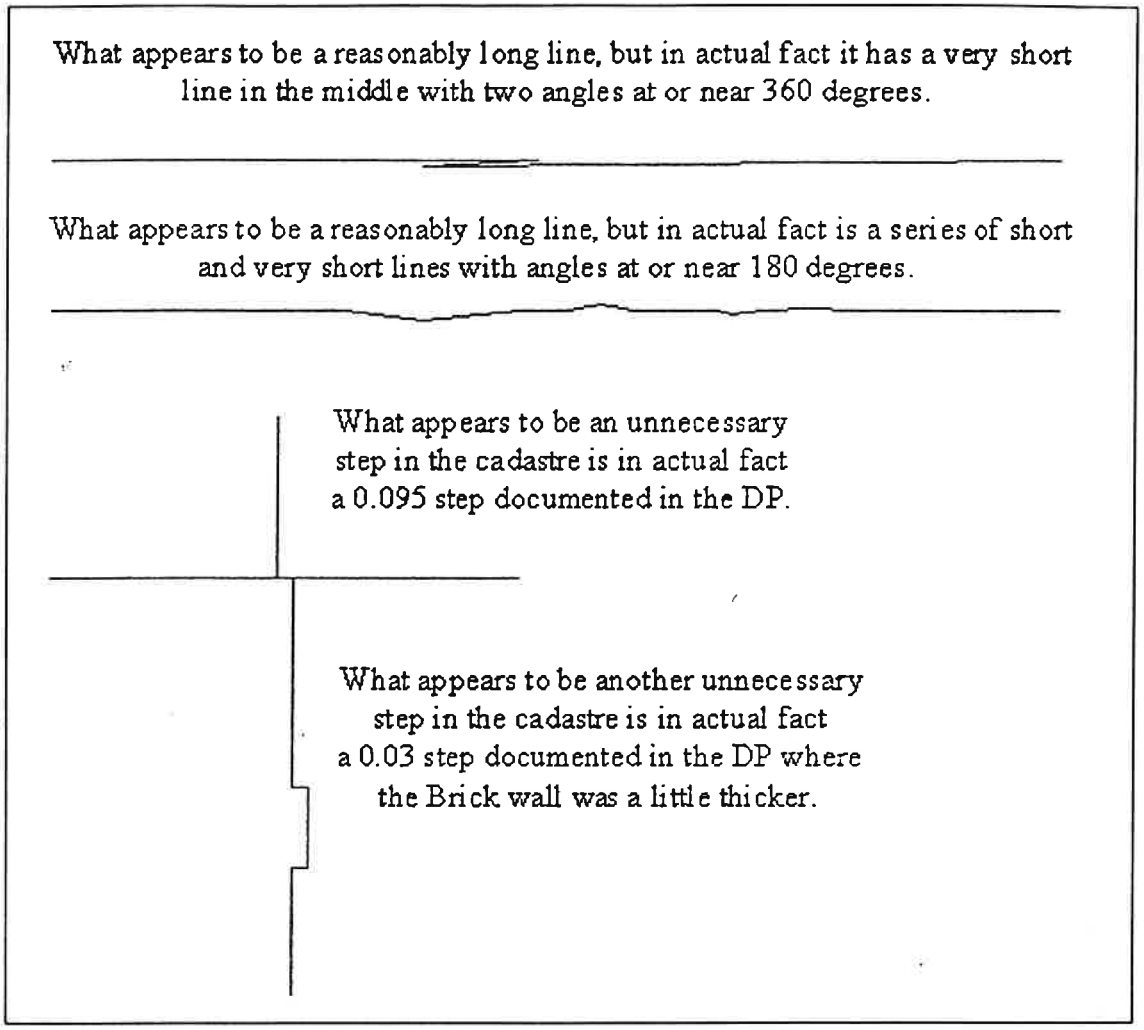
The 'Shifting Cadastre' creates a number of other geometric problems that need to be addressed. Failing to provide functionality to deal with these problems will cause the affected features to be placed poorly relative to the new cadastre. Depending on the size of the misplacement, whether it can be found or not, and on resources being available to fix the misplacement the feature may be left in the wrong relative location.

The Spatial Adjustment Engine has carried out several Utility Upgrades on what is commercially considered typical extent and complexity. The following discusses the other geometrical problems encountered and their solutions.

Bad Topology

Bad topology refers to unexpectedly short lines in amongst lines of normal length for the area. Generally, there are many extra points in any spatial dataset than may be necessary to represent a real world feature. The reasons why there are these extra points vary, and some points may be necessary whilst others are not. There is little concern with Bad Topology where these extra points form lines with the same magnitude as generally occurs in the theme, every unnecessary point provides the potential for a slight deviation from a straight line. Where these points form lines significantly shorter than those generally in the theme, unstable shifts can be caused in the adjustment process. In some cases, where the adjustment shifts are far greater than the length of the line, they will cause divergence (the point will not converge to it's correct location). There is no exact rule in this regard as it is case dependant. One rule-of-thumb is that the shortest line should be ten times larger than its expected shift, but other factors come into play and can reverse this otherwise valid rule.

The DCDB is especially prone to have short lines. Some of these lines result from valid boundary lines such as along a common boundary of an "as occupied" subdivision.



Other short lines are caused by the:

- GIS technique of storing arcs as a series of short chords
- use of tiling to store contiguous themes into smaller, more manageable, rectangular tiles

Whatever the reason for these extra points occurring, there is no real way of knowing if these points should be there or not. Although it is possible to find them and display them, putting an operator onto the job of removing them is usually not an option due to the costs involved with doing the work, retrieving Deposited Plans, etc.

In Utility Data, short lines connect closely located equipment and represent feeders going into property. Hence, it is important that these points have their relative placement preserved in an adjustment situation.

The SAE solves this problem by using the following this process. Whenever a short line is found, as defined by a user tolerance, directions and distances are stored to all points connected to the first point (start node) on the short line, as well as to all points connected to the other point (end node). This has the effect of bracing the

points connected to the other point (end node). This has the effect of bracing the short line's points up, much like a surveyor's braced quadrilateral surveying technique. It also has the effect of adding longer lines to the set, which is part of the Spatial Adjustment Engine's solution to the shortest line rule mentioned above.

Vertical Topology

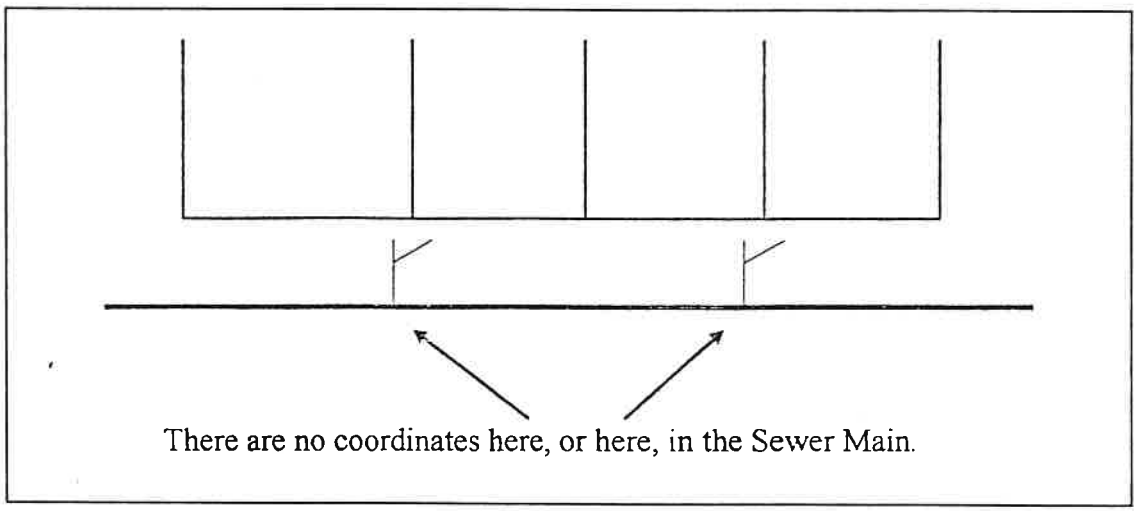
Vertical Topology is a problem for GIS technology. Using coordinates in one layer for other purposes in other layers creates vertical topology. An example of vertical topology would be using the DCDB to define administrative boundaries. Sets of coordinates in the DCDB are duplicated into the administrative layer, causing the administrative layer to plot over the top of the DCDB. The difficulty is that these points are copied, and an update in the DCDB has to be somehow duplicated into the administrative theme to maintain this verticality between themes. Due to the lack of tools and the complexity of this work, this job is often done manually.

The Spatial Adjustment Engine handles this problem by modeling GIS data differently. The typical GIS model stores polylines as a series of sequential coordinates through which the line is drawn. The Spatial Adjustment Engine stores each coordinate once only and assigns a number to each point. Each GIS theme is held in a separate table and each record stores two point numbers through which a line is drawn. The GIS model is definitely three or so times faster at redraws, but lacks the data modeling needed for this type of adjustment or to manage Vertical Topology.

Implied Vertical Topology

Implied vertical topology occurs when spatial objects should share common points in the database but do not. Implied vertical Topology, on the surface, is the same thing as Vertical Topology, however it is handled quite differently. Vertical Topology occurs when two features share common points, such as abutting parcels in a DCDB. Implied Vertical Topology occurs when a line is drawn from a point on another line, but the other line does not contain a point with the starting coordinates.

Such an example occurs in water and sewerage pipes.



For database modeling purposes, a main pipe is stored as one item in the database, and as one item in the GIS. It does not matter how many pipes are connected to it, the pipe has the one set of dimensions, the one grade, coefficient of friction, etc. In the GIS, two points are used to represent the pipe, one at the beginning and one at the end.

Each side pipe is 'snapped' to the main so that it draws correctly. The 'implication' is that there is vertical topology that must be maintained between the side pipes and the main pipe.

The Spatial Adjustment Engine deals with this problem in a two step process.

The first step happens in the data preparation stage. A command is run which goes through each line in each layer and finds all points which are within a very small tolerance of being on the line. Directions are stored which act in the adjustment to keep the point on the line.

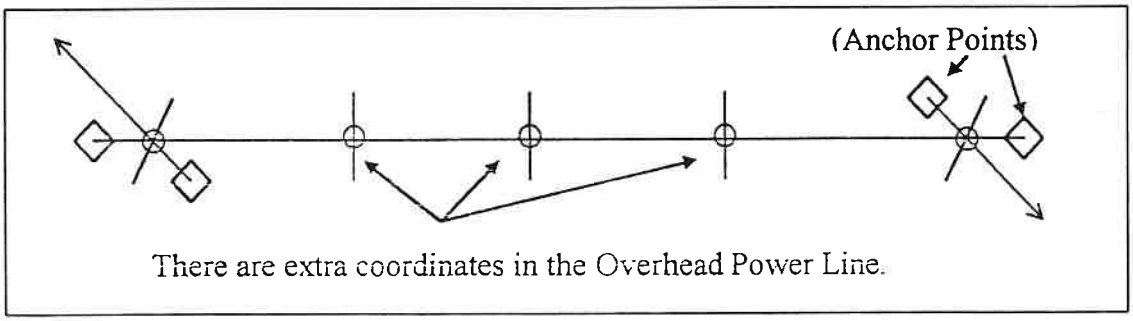
However, because the shifts at the two ends on the main are rarely the same as those part of the way along the main, it is likely that the start point for the feeder pipes will move a little from the main pipe.

The second step in the process occurs after the adjustment. This process simply finds the same points and snaps them back onto the main pipe.

Preserving Long Lines

Long straight lines occur in various features, and even occur across features. Cadastre provides examples of long straight lines across features, both along the road frontages and along back boundaries. Road Centrelines provide examples of features containing long straight lines, often broken by side streets. Overhead power lines are made up of long straight lines, broken by pole locations, between anchor points. Each pole can be safely assumed to be on a perfectly straight line due to the very large tensions in the cable. Each straight line in an overhead power line is independently anchored at both ends due to the tension used to reduce sag. The poles between these anchor points are placed on a straight line to reduce lateral tensions, which would cause the pole to lean.

Sewerage and water pipes are manufactured and laid in long straight lines with constant grade, but when these are modeled as having only the start and end points they do not need to be treated to preserve their straightness. If they do not contain vertices between the two ends there can be no deflection.



There are extra coordinates in the Overhead Power Line.

The Spatial Adjustment Engine deals with this situation in two steps.

The first step happens in the data preparation stage. A command is run which goes through each line in each layer and finds all lines that contain a minimum number of points that form a straight line within a small tolerance.

Directions are stored which act in the adjustment to keep all the points on the line.

However, because the shifts on individual points along the line are rarely the same as those for the total line, it is likely that some points will move a little from the line. For example, these varying shifts might occur due to the front boundaries in the DCDB being straightened up, or because the anchor is located at the half angle in the cadastre and the angle in the cadastre has been changed. The second step in the process occurs after the adjustment. This process simply finds the same lines, derives the line of best fit, and snaps these points back onto the line. Extra care has to be taken with points that form the intersection of two or more long lines.

Preserving Associativity in Rural Areas

It is possible for utility services to run for several kilometers down a perfectly straight rural road, with one property on each side. In these situations there simply are no nearby points in the cadastre with which to form inferred topology. However, it is expected that the point from which the utility service enters the property will remain the same distance from the road frontage(s).

The Spatial Adjustment Engine overcomes this problem by checking that sufficient observations (directions and distances) are formed for each point. In this case, the service is at the end of a utility line, hence the only observations that can be formed are the direction and distance back to the previous point on the service. There are no nearby points in the old cadastre, so observations cannot be formed to build inferred topology. However, there are one or two nearby lines, being the road boundaries. The SAE finds these lines, builds directions and distances to their end points, and adds these observations to the ones from the point at the other end of the utility service. This provides proportioning both along and across the road, depending on variations in the road length and width, thus the relative position is preserved correctly.

Preserving the Location of (Annotation) Points

Isolated Points do not normally occur in Utility Layers, as they typically represent the flow of water, electricity, gas, sewerage, and hence make up a network of connected lines. Some assets such as street furniture and satellite telephones however could be represented as points.

The most common unconnected point in GIS is the annotation point. There is usually such a point for every polygon. Often an algorithm in the GIS generates these locations, but there are many instances where they have been manually placed for cartographic reasons. For example, 'Battle Axe' blocks typically cause automatic annotation routines to give poor cartographic placement of annotation. The potential

to lose the cartographer's placement of annotation makes it important to treat annotation points properly in an upgrade situation.

Some GIS platforms will generate annotation points located just inside the polygon. With ArcView 3.1, the command aPoly.ReturnCenter will return the centroid of the bounding rectangle if the centroid is inside the polygon, otherwise the point is moved in the X direction to be inside the polygon. If the centroid happens to be 0.05m inside the polygon, that point is returned. ArcView's help does not specify just how far inside the polygon the point is moved if the centroid is not inside the polygon, but some manually checked examples indicates about 3 metres, in real-world coordinates, is used.

If the shift from an adjustment moves the polygon perimeter such that the centroid or the annotation point is outside the polygon, then subsequent plots will mislabel the polygons and various spatial analysis techniques are disabled. For example, moving attributes from one polygon theme to another using the centroids in one theme to select the matching centroid in the other will not work. Depending on the future usage of the theme, this may be a considerable problem.

For these and other reasons, there are valid cartographic and topological reasons to relocate unconnected points with the same care as connected points in a Utility Upgrade.

The SAE treats isolated points, such as annotation, initially as points on the end of a service, and hence searches for nearby lines to form implied topology. However, the search distance is expanded in stages up to 100m. If one or more nearby lines are found, directions and distances are formed to two points on each of those lines. The search ends at 100m, as any point more than 100m away from any line can be considered spatially independent of those lines, ie the point was probably not carefully located against nearby assets or parcel boundaries.

SOPHISTICATION LEVEL 2

With the extra level of sophistication one can expect better placed assets under the shifting cadastre scenario, with a far wider set of spatial/geometrical circumstances being supported.

Naturally, to achieve this level of sophistication it is necessary to add extra observations. Since these observations take next to no time to generate, and have little effect to the subsequent processing time, it is a small price to pay.

The total effect on the upgraded utility layers, and the potential to add other observations for other circumstances, is what makes this approach the most appropriate method for dealing with the shifting cadastre problem. Each point is moved to an optimal position taking into account the points it is directly connected to, the points around it, and any larger structures (e.g. long straight lines) it may belong to.

RUNNING a UTILITY UPGRADE USING the SPATIAL ADJUSTMENT ENGINE

The Parametric Adjustment Technique has been used to solve countless Surveys, which incorporate many different topological scenarios. As implemented in the Spatial Adjustment Engine, it has solved numerous typical Utility, Cadastral and Centreline Upgrade problems.

The following process is taken from the sample SAE Client Application, which may be downloaded from Spatial Web Consulting's Web Site, *http://www.SpatialWeb.com.au*. The sample application is supplied with VB5 source code. Its purpose is to take you through the seven steps needed to carry out a Utility Upgrade using the Spatial Adjustment Engine.

Step 1

The first step is to log into the Spatial Adjustment Engine (SAE). This identifies the user and tells the SAE what user name to print on the reports.
This also tells the SAE where the working directory is for this particular job. Multiple jobs can exist on the PC, with each job representing a different area undergoing an upgrade.

The projection, either AMG or ISG, is also defined at this stage.

Step 2

Each theme is transferred from the GIS format into the SAE. In this client application the ESRI Shape File format is used.

The two Cadastres must be loaded, the old cadastre to which the utility data was relatively positioned, and the new cadastre to which the utility data must now fit.

Each Utility Layer must also be loaded. In this case there are three layers. The first is Water, the second is Sewerage, and the third is the Road Centreline. Road Centreline is not a Utility, but in this instance it is spatially dependent on the original cadastre and needs to be shifted.

Step 3

This step describes the various themes, in terms of plotting parameters and topological treatments that are required. Two forms are also optionally displayed. These forms provide a GUI interface to the Spatial Adjustment Engine, allowing various settings to be changed and providing zoom, pan and other interactive functions to be carried out.

Step 4

Step 4 goes through the two cadastres, and identifies common points. Points in the Old Cadastre that have an equivalent point in the new cadastre will be shifted to the new cadastre's equivalent. Points in the Old Cadastre that do not have an equivalent point in the new cadastre will be shifted to where they might be in the new cadastre using the various directions and distances (observations) that will shortly be created.

Step 5

This step sets up all the parameters for the adjustment, creates all the directions and distances, runs the adjustment, fixes Implied Vertical Topology, and carries out various statistical reports.

Step 6

Step 6 allows the user to zoom in and pan around to inspect the results of the adjustment. In the remote chance there is a problem, steps can be taken to remedy the problem and reprocessing undertaken.

Step 7

This step creates upgraded themes, in this case using ESRI's Shape File Format, holding the upgraded water, sewerage and road centreline themes. These shape files may be viewed using ArcView, or the free ArcExplorer. They also contain the results of the statistical analysis carried out in Step 5.

These statistical results can be quickly viewed and the upgrade assessed, leading to a decision on whether to accept the adjustment or to run it again with some variation to the parameters used.

CONCLUDING REMARKS

The applicability of the Parametric 'Variation of Coordinates Technique' to Utility Upgrades has been explored in some depth. The various mechanisms for building observations that this technique needs has been explained for the various geometrical combinations of linework found. The levels of sophistication have also been explained.

The development of an application that allows for further experimentation in 'real world' environments has also been achieved. This application is called the Spatial Adjustment Engine, and is available for download, for evaluation purposes only, from the Internet Location *http://www.SpatialWeb.com.au*. The download comes with sample data from South Australian, courtesy of DEHAA and SA Water.

The downloadable client application can be configured to run on other datasets, all that is necessary is to correctly describe the two cadastres and the utility themes to the SAE. Further work on the client application would enable it to work with data from other GIS platforms.

It is the firm belief of the author that the level of sophistication described in this paper will enable the Parametric Technique to yield consistently superior results to any other upgrade technique.