SPATIAL WEB CONSULTING

The Spatial Adjustment Engine White Paper

March 2003

Table of Contents

Table of Figures

1 Executive Summary

Many organizations use Digital Cadastral Maps to maintain ownership information, and many have also located their utility and zoning layers against these cadastral maps. The increasing availability of GPS has highlighted the spatial inaccuracies of these themes, and this inaccuracy in the Cadastral Layer effectively prevents GPS located features from be used directly in large-scale maps.

The GIS and Surveying communities must either downgrade their GPS coordinates to fit the digitised themes, or improve the spatial accuracy of these cadastral and spatially dependent themes. The problem is that if the cadastral theme is improved the utility (and other) themes are then in the wrong location relative to the cadastral theme. To fix this, all themes must be moved to fit the new cadastral theme, but this is difficult logistically as many of these themes are maintained by separate organizations.

In theory these digitised themes will eventually become spatially accurate through maintenance cycles. This has not eventuated due to lack of suitable tools to cost effectively carry out this processes.

This demand has created the need for software solutions that provide efficient and easy-to-use property parcel maintenance tools.

The Spatial Adjustment Engine offers the GIS community the first real tool to manage the ongoing upgrade of spatial data.

This paper examines the two versions of the Spatial Adjustment Engine to address the main task of upgrading the Cadastre, then of moving spatially dependant themes such as Utility, Zoning and Annotation to match the spatially improved Cadastre.

1.1 Two Spatial Adjustment Engine (SAE) versions

The Spatial Adjustment Engine comes in two versions, being Cadastral and Utility Upgrades, and each is optimised for the process it addresses.

1.1.1 Cadastral Upgrades

The SAE combines State Survey Marks (SSMs), GPS Coordinates, Title and/or Survey Dimensions and the Cadastral Layer to allow for the rigorous upgrade of the Cadastral Layer, as well as the output of the Dimensions in a variety of Spatial and Relational formats. This version is mainly used interactively as the major process is data entry, data validation, and statistical reports and analysis.

1.1.2 Utility Upgrades

The SAE has been well proven at managing the shifting of Utility and Zoning Themes, and Annotation Layers as the Cadastre is upgraded. This version is totally automated via scripts, taking the user’s data in a predefined agreed format and automates the entire upgrade process from loading the area’s data through the upgrade process to producing the upgraded theme.

2 Introduction

The Spatial Adjustment Engine features an easy-to-use point-and-click Graphical User Interface and a simple and comprehensive scripting language. All commands are available in the scripting language and in the standard Windows interface. The SAE provides all the necessary tools to import data from a variety of spatial formats, and a comprehensive set of tools is available for data entry, data validation, adjustment, statistical analysis and final export.

This paper describes many of the major highlights of the Spatial Adjustment Engine, and provides many screen examples to help the reader understand the scope and purpose of this application.

The Spatial Adjustment Engine is a '**Vendor Free**' application, meaning that it only uses freely available components from other vendors. All the data held for the spatial upgrade is held in a Microsoft Access database, which means that data can easily be transferred to corporate systems and used as required by other systems. For example, during the Cadastral upgrade significant vector data is collected from the Survey Plans, which could be maintained in a database serving the Survey Profession.

The two Upgrade Methodologies are briefly elaborated on as follows:

2.1 Cadastral Layer Upgrade Methodology Explained

The Cadastral Layer has been digitised from paper maps, and there is much knowledge in the industry about the inaccuracies inherent in this important dataset.

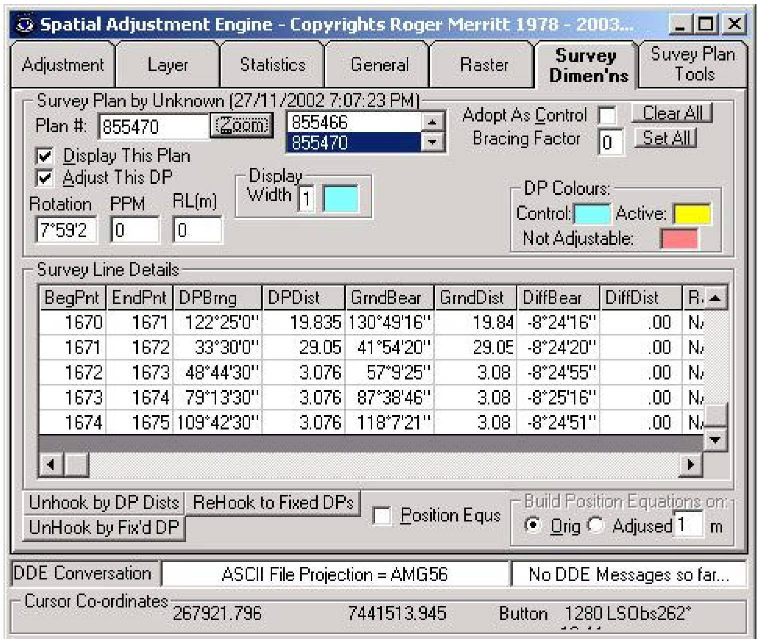
The process of upgrading the Cadastral Layer is one major problem in itself, the size and scope of the task is very large, and the mathematics needed is complex. The only way the cadastre can be upgraded is area by area, but to maintain a current cadastre the upgraded cadastre must be inserted back into the master layer. This means that a buffered area of perhaps several hundred metres must be adjusted to accommodate a transition from the original cadastre to the repositioned upgraded cadastre. The problem of adjusting the multitude of Survey Plans, tracking down data entry errors and erroneous plan dimensions, and sorting out what lines to adopt from Survey Plans with different dimensions is another difficult logistical and mathematical problem.

The SAE deals with all of these problems in the following manner:

First, the Cadastral Layer is loaded into the SAE, and the polyline structure of the Cadastral Layer is translated into a Point-Node structure, which means that every unique coordinate is given a unique point number, and the lines between each joined pair of points is also given a unique number. The State Survey Marks and GPS points are loaded into a different layer, which enables them to be held fixed in the adjustments that occur later.

Next, the many dimensions (both the bearings and the distances) are entered against their Survey Plan Numbers. Each dimension is located against the Cadastral Layer by a simple mouse-down-up action that triggers a form that enables the bearing and distance to be entered. Much effort has been put into reducing the data entry and validation times.

Figure 1 shows the SAE's Survey Dimension Summary form:



This form provides much of the DP based functionality and settings. Plans can be used in the adjustment for their dimensions or be used as Control to suit circumstances, etc.

Another important feature is the list box containing all the dimensions for the current DP. This list can be scrolled and sorted on any field, assisting with the task of finding and fixing errors.

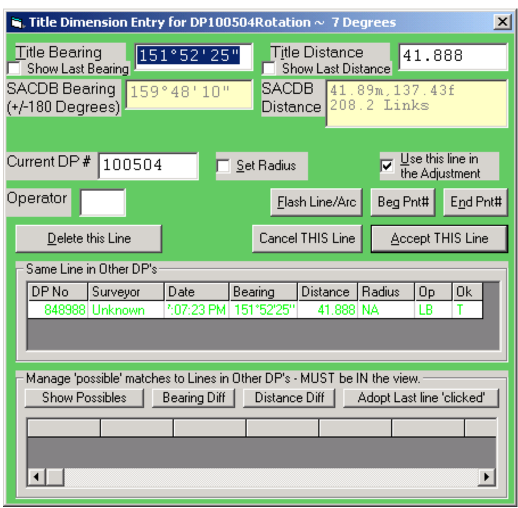
Figure 1 - Survey Dimension Form

A variety of tasks can be started from here, including zooming to the Plan in the spatial viewer, editing any survey dimension, modifying how the current Plan is treated in the adjustment run, its display, etc

The form in Figure 2 is used for entering and editing the Title Dimensions, i.e. the Bearing and Distances on the Survey Plans.

This form provides all of the Dimension Entry and initial validation routines.

A wide variety of **formats and units** can be used to speed data entry, and the SAE keeps track of dimensions that have been entered previously against another Plan.



Individual lines have various flags, including operator codes, radius, and whether the line is valid and can be used in the adjustment.

The two points at the ends of the lines can be flashed, which can be very helpful in complex situations with many short lines.

Figure 2 - Title Dimension Form

The validation tools are then used to search for errors. There are several tools, each with a greater degree of refinement and each with different mechanisms to find the different types of errors.

Using only observations built from the Survey Plan dimensions, the Survey Plan data is then adjusted. Problematic areas in the Survey Plans can be found using the SAE's statistics tools, which are then fixed with various editing tools. Typically several iterations of this process are required.

When all the Survey Plan Data has been fixed the job of upgrading the Cadastral Layer can be commenced.

This requires a few different settings in the SAE, and another adjustment run. These settings tell the SAE to hold all the adjusted Survey Plan coordinates as control, and to build the observations from the Cadastral Layer coordinates and topology.

As an example, one project comprising 3757 parcels and 11053 points in the Cadastral Layer, 884 Survey Plans with 16,517 dimensions, and just 54 SSM/GPS points resulted in an adjustment with a standard deviation of just 0.031 metres in Survey Plan Distances, fitted to 10 GPS check points within 0.2m. This dataset had local shifts ranging from near –3m to +33 metres, meaning that the Cadastral Layer was out by up to 33 metres in some places. The SAE is capable of adjusting larger datasets, but this is about optimum from a project management perspective.

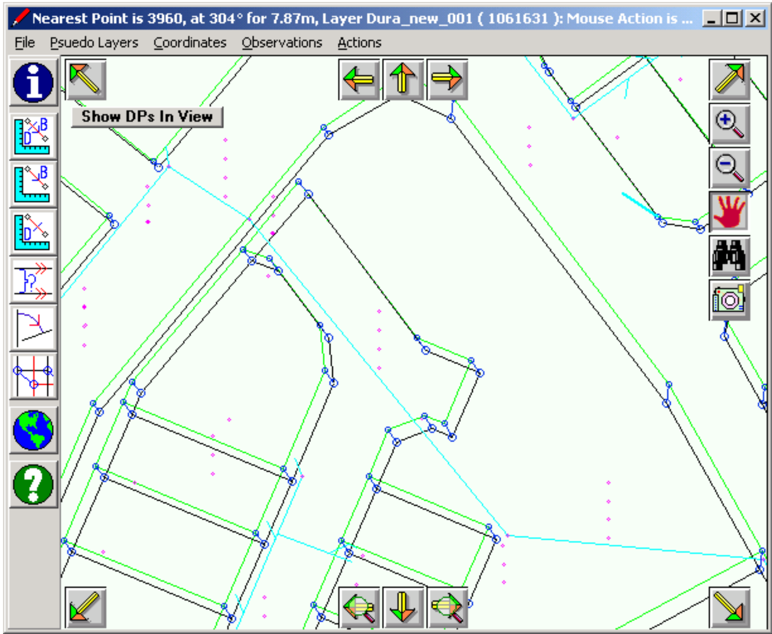
2.2 Utility Upgrade Methodology Explained

The Utility Layers, together with other layers such as annotation layers, have been digitised against a cadastral layer in order to produce consistent maps. There is little value showing the water supply for a particular parcel terminating in a neighbouring parcel, so these layers are deliberately downgraded to fit the Cadastral Layer.

With upgrade to the Cadastral Layer, the utilities need to be upgraded to maintain their local positioning (spatial relativity) with the Cadastral Layer.

The Spatial Adjustment Engine has **sophisticated point-matching routines** that match points in the original Cadastral Layer with points in the new 'upgraded' Cadastral Layer. These shifts are then used to manage the upgrade of the utility (and other) layers to fit the new Cadastral Layer.

Figure 3 shows the new Cadastral Layer in Green, the original Cadastral Layer in black, the joins between the two Cadastral Layers in blue, and the utility layers in other colours.



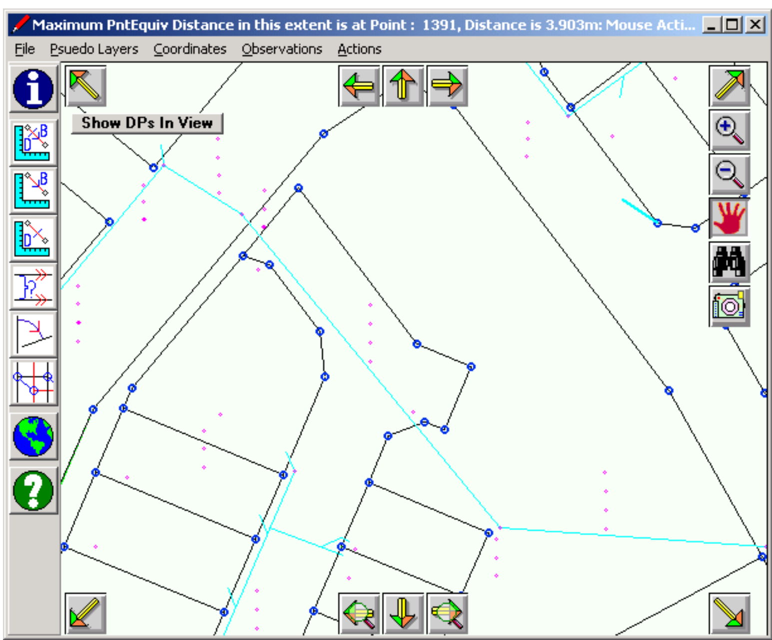
The **Green** Layer is the 'Destination' Cadastre.

The **Black** Layer is the 'Old' Cadastre, against which the **Cyan** Water and **Magenta** Annotation layers have been collected.

The **Blue** 'Joins' between the two Cadastres have been automatically generated by the Spatial Adjustment Engine, and create "*Spatial Relativity*".

Figure 3 - Utility Adjustment showing Equivalent Points

Figure 4 shows the same view after a successful adjustment by the Spatial Adjustment Engine.



After the Upgrade the **Black** Cadastral Layer obscures the **Green** Cadastral Layer, and the **Cyan** Water and **Magenta** Annotation layers have been moved to best maintain "*Spatial Relativity*".

The extremely good fit of the old cadastre over the destination cadastre indicates the upgrade of the Utility and Annotation Layers has been completely successful.

Figure 4 - Utility Adjustment showing Adjusted Themes

Comparing the two images will show differing sized shifts in different directions. Also note that the utilities have maintained their location relative to the new 'upgraded' cadastre.

It should be pointed out that the Utility Upgrade functionality assumes the SAE has not been used for the Cadastral upgrade, however better results should be expected quicker if it is.

3 Legend Editor

The SAE's Legend Editor (shown below) provides the usual tools to set colours and line thicknesses for each theme of spatial data, but also provides settings for each theme for adjustment purposes.

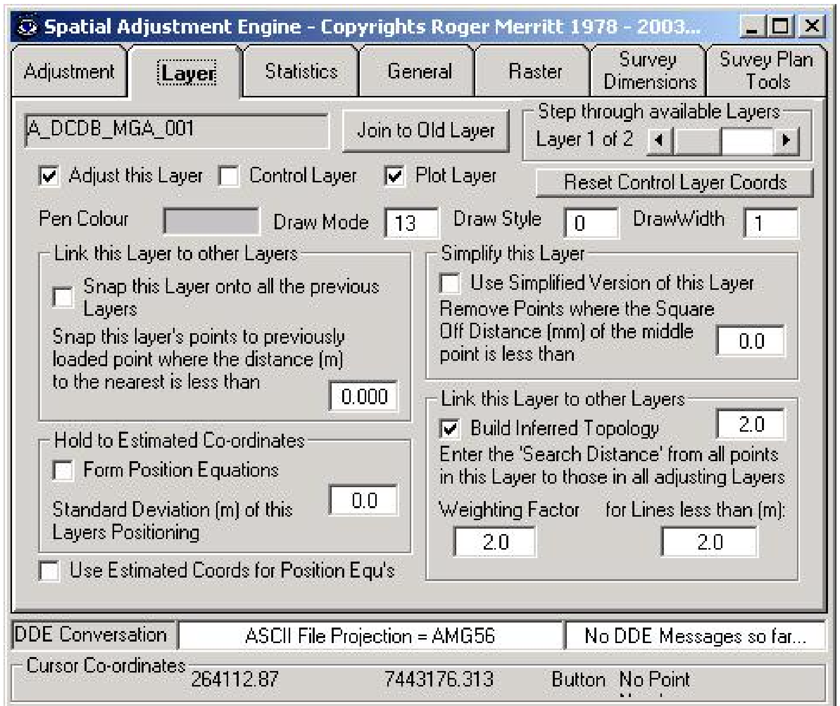


Figure 5 - The Legend Editor for Spatial Layers

By far the most important concepts are "Inferred Topology", "Vertical Topology", and "Implied Vertical Topology". These concepts can be researched through URLs mentioned later in this document.

A great deal of time has gone into developing methodologies and code that allow the widely varying spatial Topologies to be stable and representative in the observation tables that are produced in the adjustment process.

This form caters for the varying adjustment scenarios, which exist in both Cadastral and Utility adjustments. Some themes are fixed and not open for adjustment, such as State Survey Mark themes.

Other themes are best treated with Position Equations, such as GPS Themes. Cadastral Themes need little of no Inferred Topology but themes for Utilities, Zoning and Annotation Layers are totally reliant on Inferred Topology

4 Map Data Display

The SAE's Map Display can vary considerably depending on the information being displayed and the intended purpose.

Figure 6 shows the Cadastral Layer during the adjustment phase, small black circles are drawn over each vertex as the matrix goes through its Cholesky run:

The following diagram explains the Map View tools for the Cadastral Upgrade configuration of the Spatial Adjustment Engine.

The provision of tools on the Map View has proved convenient and very effective for the operator.

Figure 6 - A Utility Adjustment doing the Cholesky process

The provision of Panning and other tools on the Map View makes working with the Spatial Adjustment Engine very easy at large scales. Instead of having to select another tool to pan a little and reselect the tool you were using, all you have to do is click on the Panning tool for the direction you want to pan then carry on with the existing tool.

In the Cadastral Adjustment process, accurate surveying data is collected from Survey Plans (official records of subdivision and consolidation) and connections to State Survey Marks or GPS Coordinates are entered.

Figure 7 shows the 'active' Survey Plan highlighted in yellow, the original position of the Cadastre, and joins from Control points (Red Dots). The Camera and Information button can also be used to display the relevant raster 'Survey Plan' image for any parcel in the cadastre. These images can be displayed on the same PC or on a nearby PC via a network connection.

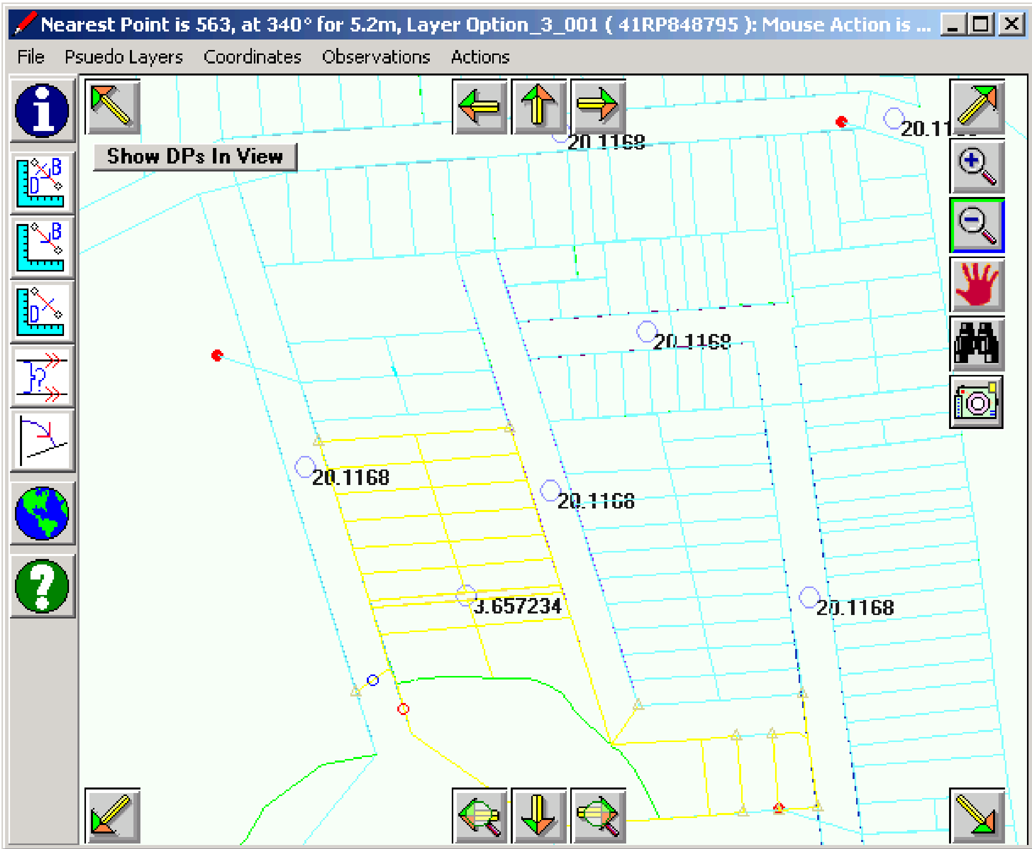


Figure 7 - A Cadastre with Survey Plans prior to Upgrade

Note that there is survey joins from the two red dots stretching to the South East for about 40 metres.

Apart from the joins to Control Points, all Survey Plans are entered against the Cadastral Layer. This greatly improves data entry speed as points in the Cadastral Layer are used to identify common points between Survey Plans, thus integrating the Survey Plan data. Further, it connects the Cadastral Layer to the Survey Plans, which means the cadastre can be moved to its optimal position after the Survey Plans have been adjusted.

Figure 8 shows the upgraded Cadastre and Survey Plan Layers after an adjustment involving SSM's, GPS Coordinates and Survey Plan Dimensions. Note that the cadastre has moved to the control points, and that the dimensions in the cadastral layer now significantly approach the Title and/or Surveyed dimensions. Further, the unsurveyed boundaries have moved to fit the upgraded cadastre yet significantly maintained their original shape.

Note that the Cadastral Layer has been moved to fit over the GPS Coordinates, which were collected to fix those cadastral corners.

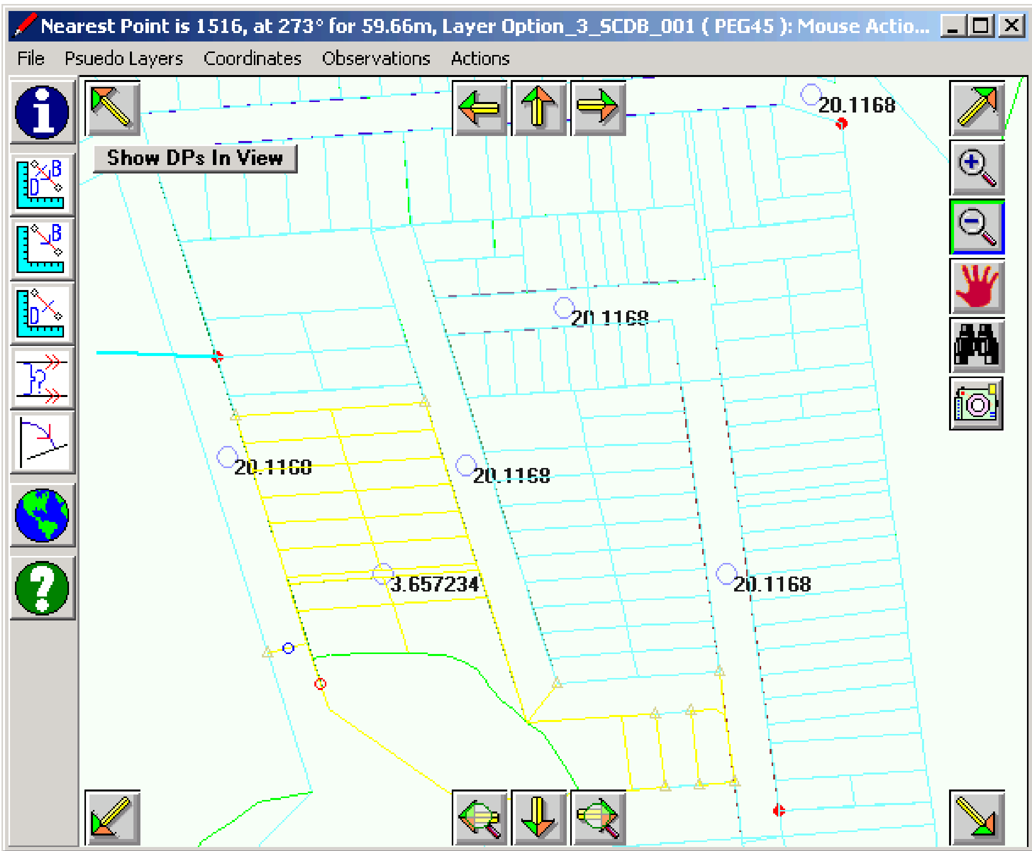


Figure 8 - A Cadastre with Survey Plans after Upgrade

The overall statistics of this adjustment were:

- The Standard Deviation of all valid survey/title distances was 0.031m, but there were some cases where large errors had to be kept to improve areas with only very old plans showing general locations
- The Standard deviation of the GPS coordinates was 0.1m
- The fit to unused GPS Coordinates was generally 0.2m, but all the larger miscloses were in areas where there were known problematic plans
- Based on 52 State Survey marks, 857 Survey Plans comprising 16,517 dimensions, 3757 cadastral Parcels, an **estimated one hour per Survey Plan** is needed to complete all the processes, being data loading, data entry, data validation and correction, adjustment and export.

5 Survey Plan Entry and Editing

There are two forms for managing Survey Plans and Survey Dimensions. The first, the "Survey Dimensions" form, manages data at the Survey Plan level whilst the second form; the "Title Dimension Editor" manages data at the dimension level.

5.1 The Survey Dimension Summary Form

This form shows data about the Survey Plan and how the individual Survey Plan will be treated in the adjustment processing.

Any Survey Plan can be found easily by spatial searches in the Map View, typing the Survey Plan number into the "Plan #' or selecting from the neighbouring List Control.

The Survey Dimension Form (Figure 9) also shows the 'Calculated minus Observed' values for each dimension. The 7°59'02" rotation is indicative of the azimuth difference between title dimensions and geographic bearings for the adjusted coordinates in this geographic area. The 'DiffDist' values of zero indicated that this Survey Plan has adjusted to its true shape. Other tests exist to measure how well it has converged to its true location, i.e. against State Survey Marks or GPS Coordinates.

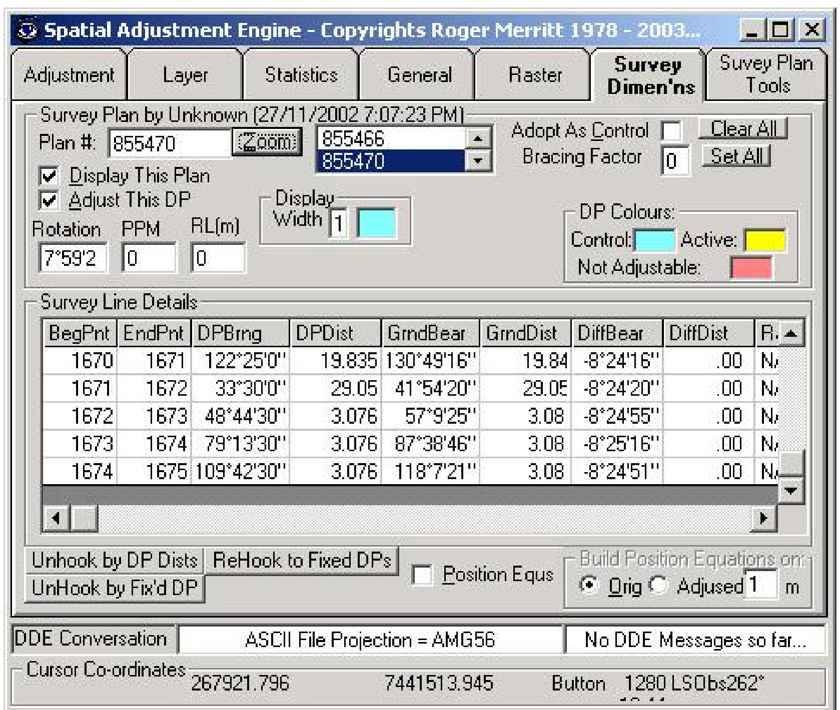
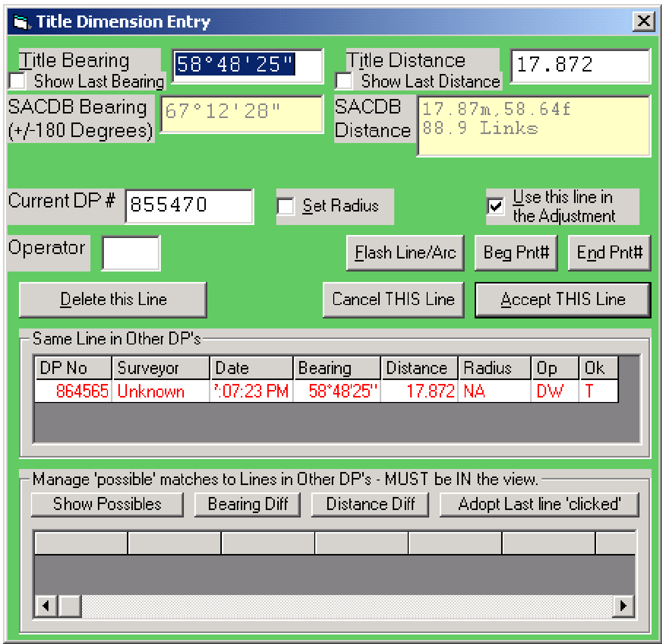


Figure 9 - Working with Survey Dimensions

Any Survey Dimension can be edited either by double clicking a dimension on the above form or selecting it on the Map View. In either case, the Title Dimension form will be displayed.

5.2 The Title Dimension Form

The Title Dimension form (Figure 10) allows for the entry of individual dimensions from the Survey Plans, or of reduced Directions and Distances from field Surveys.



The Operator Id and Current DP# number are remembered for each Session of the SAE, reducing data entry times.
If a new DP Number is entered another form is displayed to capture various data about the DP.
If the "Set Radius" is Checked then more controls are shown to allow the entry of the radius of the Arc.
Tools exist to search for similar Dimensions that may match this one.

Figure 10 - Working with the Title Dimension Form

The top line shows the values from the Survey Plan, and both values support a variety of data formats to accommodate various versions of bearings and distances, including links and feet and inches.

The second line shows the derived values from the Cadastre's coordinates. The cadastre can be displayed with either the original coordinates or the adjusted coordinates. These values are based on the current display coordinates.

Each Survey Dimension is tied to a Survey Plan, and can be individually excluded from the adjustment if the user feels the line is incorrect.

In this particular case, the same Survey Dimension has also been recorded on another Survey Plan, number 864565. If there are variations between two plans, the adjustment process will do its best to accommodate both but may allocate most of the error to one of the dimensions depending on the other dimensions, GPS coordinates and so on. These differences are typically best looked at in the statistical reports.

If during data entry of the Survey Plan's metadata the "Year of Survey" is entered the Spatial Adjustment Engine will weight the Survey Plan's observations according to the accuracy of surveying equipment available at that time.

6 The Core of the Spatial Adjustment Engine

The core of the Spatial Adjustment Engine is a Parametric Variation of Coordinates routine based on theory developed by Gauss and Cholesky over 40 years ago. This technique has been used around the world since then to adjust Traverse Networks.

This technique handles the complex problem of obtaining the optimal coordinates for complex traverse networks using observed values for angles and distances. The SAE Hypothesis is easy, if angles and distances are preserved whilst fitting exactly to key points, then the shape of the spatial feature has been preserved as best as possible.

The Spatial Adjustment Engine uses this technique for both Cadastral and Utility Upgrades, and the impressive results are proof of the viability of this technique for Spatial upgrades.

In Cadastral Upgrades, the angles and distances are taken from the Bearings and Distances that make up the Title Dimensions on the Survey Plans. This approach means that the best fit of all the Survey Plans is achieved, that erroneous data on individual plans can be identified via the validation and statistical routines provided and turned off, and that expected accuracies can be achieved.

In Utility Upgrades, the angles and distances are derived from the cadastral and utility topology, and are supplemented by further angles and distances between the themes to maintain relative topology.

The Spatial Adjustment Engine has a very powerful and effective adjustment tool, capable of handling thousands of Survey Plans, tens of thousands of parcels, and any amount of utility data in the parcel area. The upper limit of the Spatial Adjustment Engine is much greater than practical work place procedures, meaning that it is better to limit the size of individual jobs for the sake of human and computing resources.

For further information on this Least Squares Adjustment method, please refer to:

Practical Least Squares and Statistics for Surveyors, Monograph 13, School of Geomatic Engineering. The University of New South Wales, Kensington, Australia, 2052, 319pp. Harvey B.R., (1995).

Analysis and Adjustment of Survey Measurements, Mikhail, E.M. and Gracie, G. (1981).

Observations and Least -Squares, Mikhail, E.M. (1976).

Adjustment Computations: Statistics and Least Squares in Surveying and GIS, Wolf, P. R. and Ghilani, C. D. (1997).

7 Statistical Analysis in the SAE

The SAE provides various tools to help debug the data. Data validation exists at data entry to detect gross errors, but after the data has been entered a variety of tools are needed to scan for errors'

The Statistics form (Figure 11) is where these reports can be run.

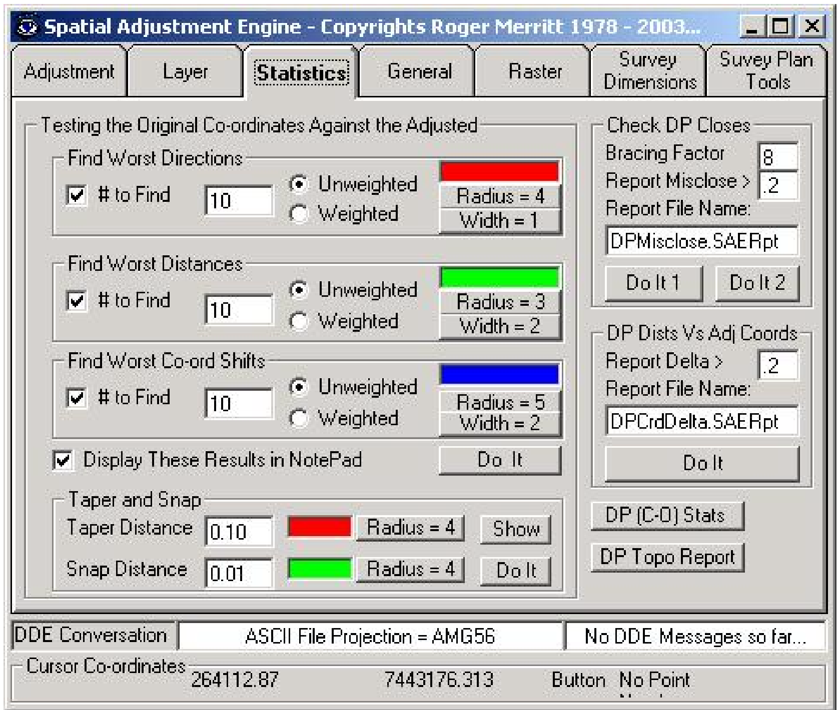


Figure 11 - Statistical Analysis in the Spatial Adjustment Engine

7.1 The "Survey Plan (C-O) Stats" Report

The "Survey Plan (C-O) Stats" report is in the following format:

909054 has a total of 6 survey dimensions, and a Survey Plan Rotation of: 7°47'11"

BegPnt	EndPnt	SPBrng	SPDist	GrndBear	GrndDist	DiffBear	DiffDist	Radius	Op	Ok
7462	7463	89°47'10"	67.620	97°26'30"	67.616	-7°39'20"	.004	NA	SL	T
7462	7467	179°42'30"	76.660	7°21'44"	76.639	-7°39'14"	.021	NA	SL	T
7463	7464	163°54'0"	22.477	171°33'15"	22.474	-7°39'15"	.003	NA	SL	T
7464	7465	20°54'20"	18.720	28°33'59"	18.717	-7°39'39"	.003	NA	SL	T
7465	7466	57°55'10"	74.764	65°35'11"	74.761	-7°40'1"	.003	NA	SL	T
7466	7467	118°49'0"	3.914	126°25'58"	3.905	-7°36'58"	.009	NA	SL	T

(etc)

Sum Absolute(DiffDist) = 233.769

Standard Dev DiffDist = 0.031

This report shows every Survey Dimension where the distance from the Adjusted Coordinates differs to the title distance by more than a tolerance. The total of all these C-O's are summed and the standard deviation produced.

This summarises an Adjustment with 16,517 dimensions, meaning that the whole mix of surveys carried out over the last 200 years by many surveyors with instrumentation of varying accuracy has a standard deviation of just 31 millimetres.

7.2 The Topology Report

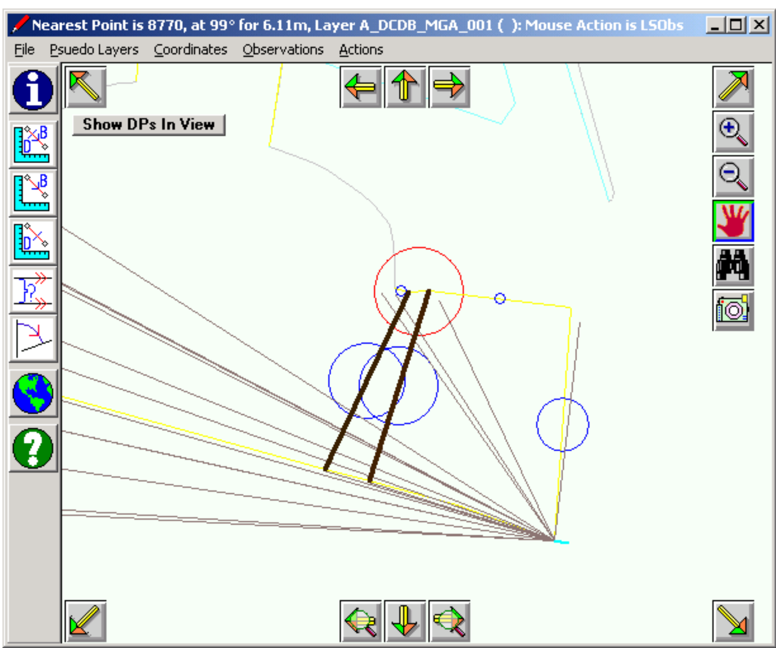
The Topology Report looks for miscloses in and between Survey Plans, and is in the following format:

DP 1	DP 2	From Point	To Point	Misclose (m)
607959	607959	7174	7175	.3
607959	607959	7173	7174	.3
603550	600801	7354	7363	.2
602047	603550	7310	7311	.7

This report summarises the interactive Topology Reporting Tool on the Map View, which is explained next.

7.3 The Interactive Topology Report

Miscloses can be detected by using an interactive facility on the Map View. Using the "Info Tool" with the "Topology Testing" option the user can click on a Survey Point and the SAE will loop through nearby dimensions and show any miscloses over a selected tolerance. The following shows such a search:



The two dark brown lines indicate where a misclose was found. Each misclose found indicates the parcel that has the misclose, thus narrowing the field of candidates. This process cannot locate the individual error in either a Survey Plan's Title Bearing or a Title Distance, but if no misclose is reported then there is little likelihood of an error being present. Note that this is also reported in a text form.

Figure 12 - Interactive Topology Testing

Red and blue circles are drawn on each line in the 'Active Survey Plan' with a C-O of greater than 0.1m, with the radius increasing with the misclose. This helps visualising where the errors are. This Survey Plan was chosen for this example, as it is a very old plan in rugged territory, hence the large miscloses.

8 Survey Plan Adjustment Management Tools

Orchestrating the Survey Plan adjustment requires management tools to set up the various parameters for the adjustment.

These tools are provided by the Survey Plan Tools form, which is shown below:

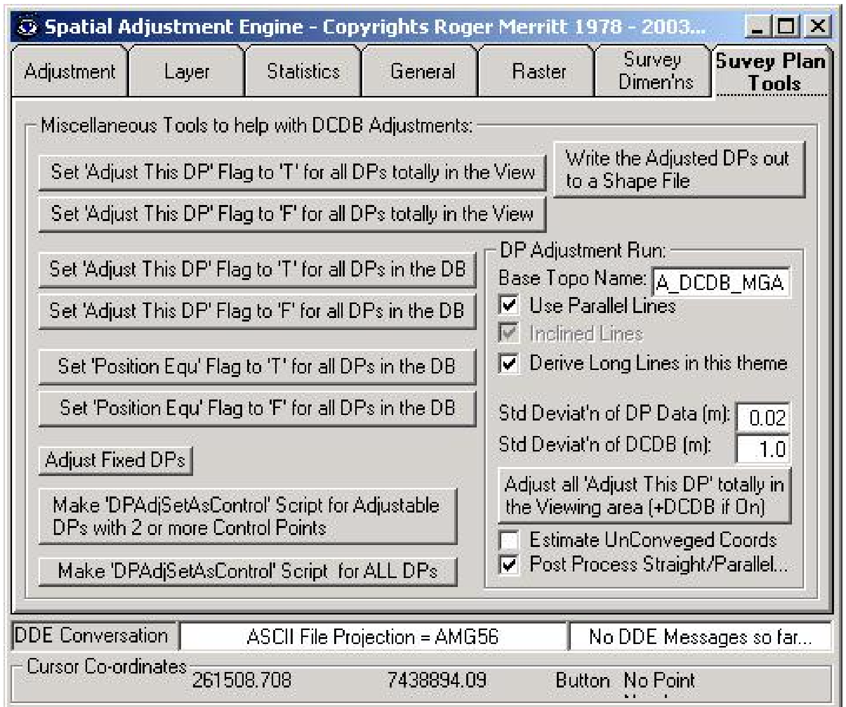


Figure 13 - Survey Plan Tools

This form provides tools to set states for all the Survey Plans entered, and include tools:

- for incremental adjustment of Survey Plans
- to set bracing observations for straight, inclined and parallel lines
- to set accuracies and run the adjustment
- to set post processing options

Individual Survey Plan parameters are set on the "Survey Dimension" Tab, and these can be used to handle odd situations like Survey Islands, which are clusters of Survey Plans that have inadequate direct or indirect connection to State Survey Marks or GPS Coordinates.

9 Cadastral and Utility Layer Adjustment Management Tools

Orchestrating the adjustment of cadastral and utility themes requires management tools to set up the various parameters for the adjustment, which the following form provides:

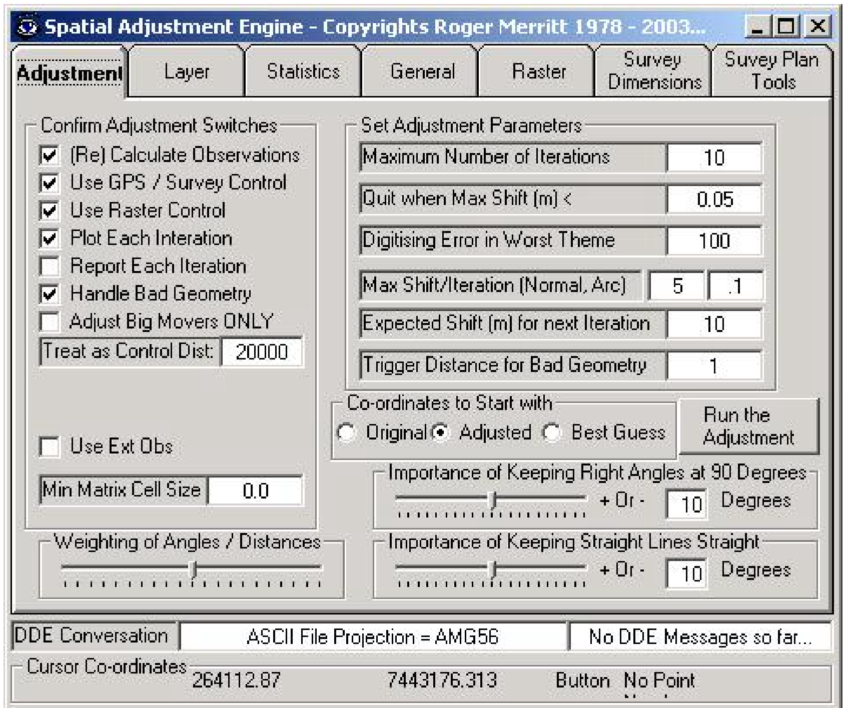


Figure 14 - The Adjustment form for Spatial Themes

This form is not usually shown for a Utility Adjustment scenario as all the parameters are scripted, and the Spatial Adjustment Engine runs unattended.

In the Cadastral Adjustment Scenario, after the Survey Plans have been successfully adjusted, they are turned to Control, meaning that their adjusted coordinates are locked down and are used as control points for the adjustment of the Cadastral Layer.

Figure 14 provides all the higher-level adjustment parameters to adjust Cadastral and Utility Layers, but layer specific adjustment parameters are held on the Layer Tab. (See the Figure 9 in this document)

10 Compatible Data Formats

The Spatial Adjustment Engine has native support for ESRI Shape Files and uncompressed ASCII Export Files, MapInfo Mif/Mid Files, Genamap Export files, and with FME Objects has support for MicroStation DGN files and the facility to use nearly all common spatial data formats.

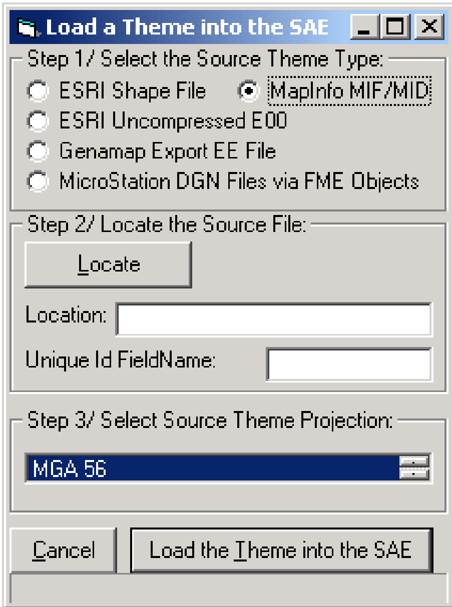


Figure 15 - Loading Spatial Themes into the SAE

The above screen is used to load all the themes into the SAE in the Cadastral Layer Adjustment scenario, whilst this is scripted in the Utility Adjustment scenario.

FME Objects has been used to access .DGN files, and will likely to be used to manage data from Small World and many other formats supported by Safe Software (http://www.safe.com).

11 Conclusion

The Spatial Adjustment Engine is the most advanced up-and-running product of its kind in the world. Major features include:

- Utilizes the most appropriate adjustment technique
- Provides extensive spatial upgrade functionality and reporting facilities
- SAE Basic to automate repetitive tasks
- An open database enabling valuable data to be extracted for other purposes
- Over 20 years of refinement of the Survey Traverse Adjustment process to further accommodate spatial data
- Supports multiple Spatial Data formats

The Spatial Adjustment Engine will assist Cadastral Custodians improve the spatial accuracy of their Cadastral Layers, bringing them into line with GPS Accuracies and making the Cadastral Layers ready for a greater array of uses. As a by-product, it will pave the way for other layers to be upgraded to GPS accuracies.

The Spatial Adjustment Engine will greatly assist those with Zoning, Annotation, Utility and other spatially dependent Layers maintain the spatial relativity of their layers as the cadastre moves (whether or not the Spatial Adjustment Engine is used for the Cadastral Upgrade).

This is a refined data management tool that can be used to realise large savings through the use of more accurate and reliable spatial data.

For further information on Cadastral (DCDB) Adjustments, please refer to:

http://www.spatialweb.com.au/papers/Aurisa2000/DCDB2000.htm
http://www.spatialweb.com.au/papers/ISSDQ_HongKong/CadastralUpgrades.htm
http://www.spatialweb.com.au/papers/cronulla/cronulla.htm

For more information on the Utility Adjustment Scenario, please refer to:

http://www.spatialweb.com.au/papers/ISSDQ_HongKong/UtilityUpgrades.htm
http://www.spatialweb.com.au/papers/apas99/APAS99Paper.htm
http://www.spatialweb.com.au/papers/ozri97/OZRI11Paper.html

Demonstrations can be arranged by emailing Roger Merritt at **Roger@SpatialWeb.com.au**, or phoning on 0419 409 347.

Pilots and Trial Versions can be arranged for both Cadastral and Utility Upgrade scenarios by mutual agreement.