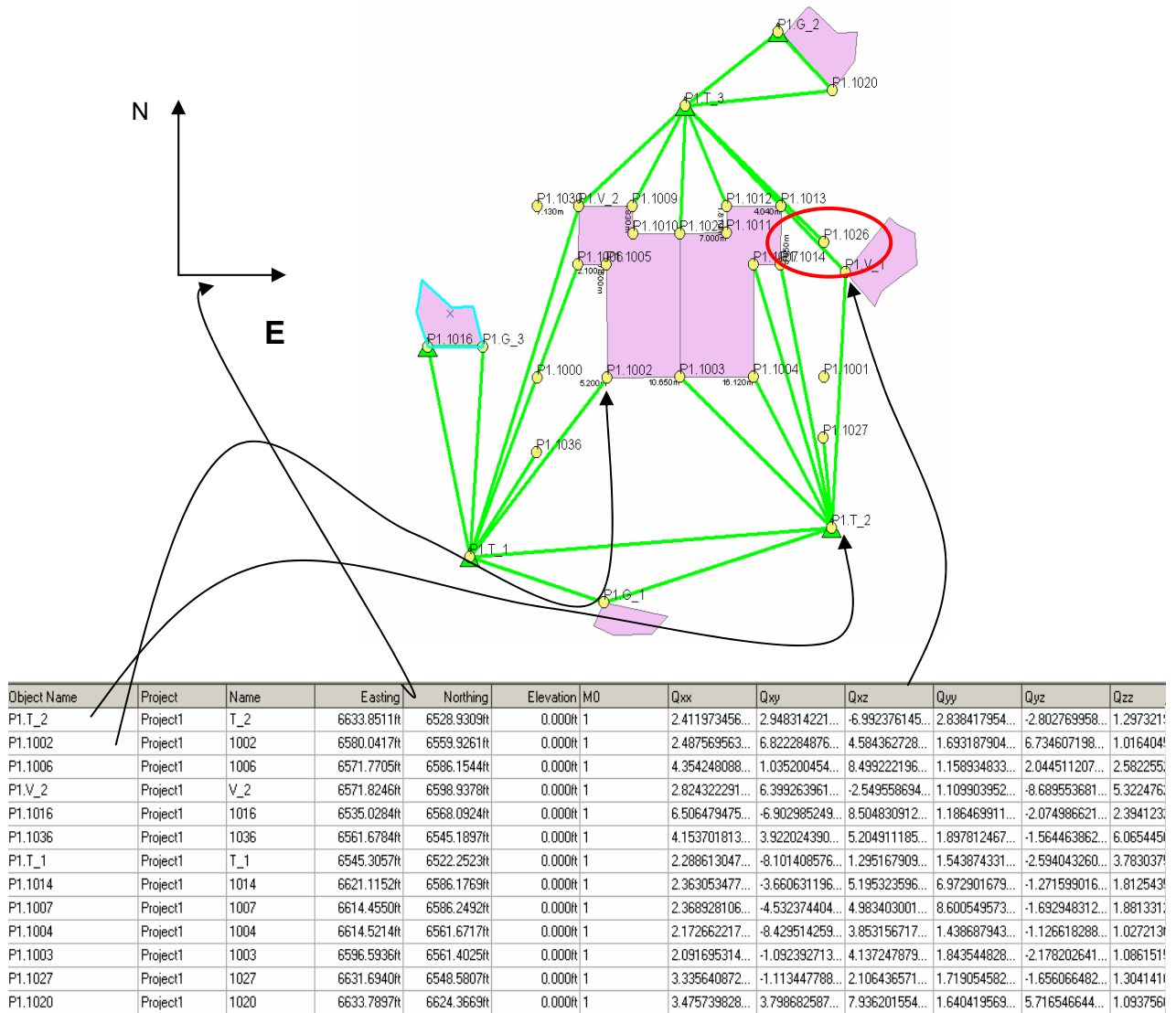


# Integrating network adjustment software within ArcGIS Survey Analyst



Geo-DBMS Case Study  
Lennard Huisman  
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**L. Huisman**

Faculty of Civil Engineering and Geosciences

Department of Geodesy

Delft University of Technology

Kluyverweg 1, 2629 JA Delft, The Netherlands

Ph. +31 15 2782795

Email: L.Huisman@Student.TuDelft.nl

## 1. Introduction

A geographic information system (GIS) is defined by Worboys (1995) as a computer-based information system that enables capture, modelling, manipulation, retrieval, analysis and presentation of geographically referenced data. The results of the operations described in the definition of a GIS are used in many different work fields. The first part of the definition describes the capturing and modelling of geographically referenced data. The basis of a GIS are the objects in the database that represent the real world, for example buildings, roads and trees. These objects are captured and modelled by surveyors. The results of survey projects are measurements with a certain precision that can be used to describe the geometry and quality of objects that can be stored in the GIS database. Although the step from measurements to object description is, according to Worboys' definition, is part of the GIS, the measurements and their precision are usually not stored in the GIS database. The quality that can be derived from precision of measurements, is usually only stored in the GIS database as meta-data about the whole dataset and not per point, although this information is available from the survey projects results.

When one manipulates, retrieves, analyses and presents the geographically referenced data in the GIS database, quality information is useful information to interpret the results of the operation. For example if one combines two parts of different datasets and the same house has a different shape in the datasets, quality is information that can justify the choice of the shape which describes the house best. Obviously if one wants to store all measurements of a survey project this is a large amount of data. Recently ESRI has released *ArcGIS Survey Analyst*, an extension of *ArcGIS* that allows one to manage survey data in a geo-database and display survey measurements and observations on a map (ESRI, 2003). In *ArcGIS Survey Analyst* the quality analysis of the survey project is based on network adjustment software developed by Grontmij Geo Informatie, *MOVE3*.

The research reported in this paper has been performed as a Geo-DBMS case study in the curriculum for Geodetic Master of Science at TU Delft. The goal of the case study in the curriculum is to independently perform a research in the field of geo-DBMS. In the beginning of this research I have asked one main question and nine sub questions:

*What is the benefit of integrating MOVE3 in ArcGIS?*

1. *What is ArcGIS?*
2. *What is MOVE3?*
3. *How is MOVE3 used in GIS?*
4. *Why is MOVE3 integrated in ArcGIS?*
5. *How is MOVE3 integrated in ArcGIS Survey Analyst?*
6. *How is the survey data stored in the ArcGIS geodatabase?*
7. *Does ArcGIS Survey Analyst have the same functionality as MOVE3?*
8. *What is a good application of ArcGIS Survey Analyst?*
9. *What quality information is available after analysis of survey data in ArcGIS?*

To answer these questions literature study has been done, people have been interviewed and a case study has been done. This paper describes the results of these activities. Section 2 will describe the *ArcGIS* concepts, section 3 describes how survey measurements are transferred into coordinates and quality description, section 4 introduces *ArcGIS Survey Analyst* concepts, section 5 shows the results of an experimental survey project, where (simulated) measurements according to the Dutch HTW'96 regulations were performed. The HTW'96 is a book that gives guidelines and requirements that survey activities have to fulfil, formulated by the Dutch cadastre. Section 6 finally gives conclusions of this case study.

Another issue one might want to discuss is if it is necessary store measurements forever. In other words who needs to store measurements in a geodatabase? Many measurements are performed for special purposes and are not useful or suitable for other purposes. This case study does not give a solution for this issue, but for the user who always wanted to store all measurements this software offers a solution. The pro's and con's of the extension have been tried to answer in this case study

## **2. ArcGIS concept**

To be able to do fast operations on GIS data it is important that the data efficiently and that the data can be accessed quickly. Besides these requirements in a database management system also integrity, redundancy, repetition, reliability and consistency issues have to be considered (*Worboys 1995*). Different users have different needs, therefore GIS software packages exist that enable the user to install different parts of the package to build a custom-made system.

*ArcGIS* consists of a family of software products that can be used to build a GIS system from different parts. This section describes the *ArcGIS* software family, the description is based on the product information on the ESRI website of July 2003. *ArcGIS* is a scalable system, which means that a GIS can be build that suits anyone, by installing the necessary products. Figure 1 shows configurations that can be build from the *ArcGIS* products. The Desktop GIS is meant for users who store their data files local and edit and analyse the data locally. Extensions have been developed that add specialised tools to the *ArcGIS* products. Examples of these

extensions are *Geostatistical Analyst* and *Survey Analyst*. If ArcSDE is added to the Desktop GIS family a Collaborative GIS is created. The Collaborative GIS makes it possible for users to access a multi-user geo-database. A multi-user geo-database has the advantages that data is stored only once and all users have access to the same and latest data.

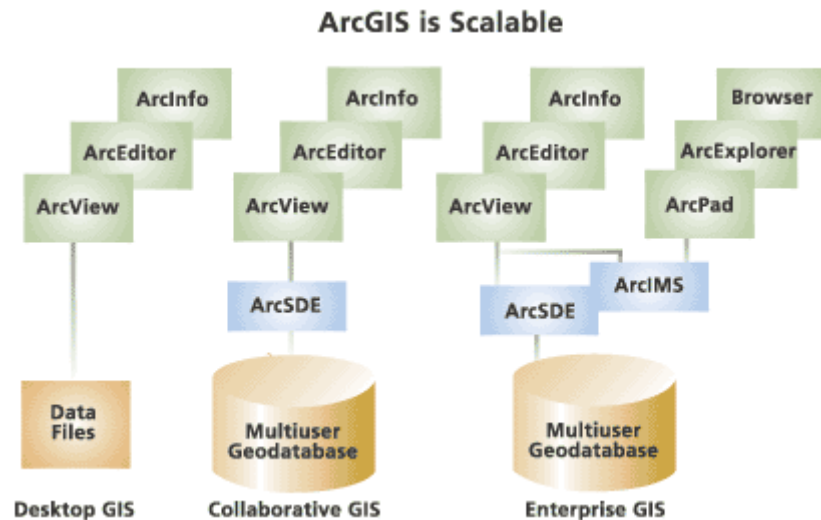


Figure 1: ArcGIS is scalable  
(source: <http://www.esri.nl/software/ArcGIS/overview.html>)

ArcSDE enables other products of the *ArcGIS* family to insert, store, edit, analyse and present spatial the data in a multi-user geo-database. ArcSDE supports various spatial database management system formats like:

- OpenGIS Consortium (OGC)
- International Organization for Standardization (ISO)
- Oracle Spatial
- Informix Spatial DataBlade
- IBM Spatial Extender Formats

Adding ArcIMS to the Collaborative GIS creates the Enterprise GIS. ArcIMS provides the foundation for distributing high-end geographic information systems (GIS) and mapping services via the Internet.

From this description of the *ArcGIS* software family it is clear that there is a broad range of potential users. Extensions are available to suit each users needs. With the *Survey Analyst* extension the surveying and GIS process is integrated in one software package; the basic concepts of this extension is developed in co-operation with Leica. The quality analysis in *Survey Analyst* is based on the *MOVE3* software of Grontmij Geo Informatie.

The process of creating a geo-database from survey data and GIS features is integrated with *Survey Analyst*. Survey projects are stored in a geo-database with *ArcGIS* based software. All GIS users that have access to the geo-database can now use the information of survey projects in the geo-database. With the extra information in the geo-database they can improve the quality of spatial analysis, because survey data is available to snap features directly to their surveyed location or create new features from survey data.

### 3. Mathematical models and testing

To be able to map objects surveyors take measurements. If sufficient measurements are taken objects (coordinates) can be modelled and stored. The link between measurements and coordinates is a mathematical model. Two models are often used by surveyors, the model of observation equations and the model of condition equations.

The *model of observation equations* uses (linearized) equations to compute unknown parameters (like coordinates) from input parameters (like measurements). The model of observation equations can be written as follows (*Teunissen, 2000a*):

$$H_0 : E\{\underline{y}\} = A\underline{x} ; D\{\underline{y}\} = Q_y \quad (1)$$

With:

$E\{\underline{y}\}$	mathematical expectation
$\underline{y}$	m x 1 vector of observations
$A$	m x n Design matrix
$\underline{x}$	n x 1 vector of unknown parameters
$D\{\underline{y}\}$	dispersion
$Q_y$	m x m variance-covariance matrix of observations
m	number of observations
n	number of unknown parameters

Underlined parameters in equation (1) are stochastic and it is assumed that observations are normally distributed. The design matrix  $A$  is assumed to have full rank and  $m \geq n$ . If  $m > n$  there are more observations than unknowns, this is called *redundancy*. The redundancy leads to an optimal solution of the network computations, in general a least squares adjustment is done to get a unique solution of the network computations. Equation (2) gives the least squares solution of the model in equation (1).

$$\begin{aligned} \hat{\underline{x}} &= (A^T Q_y^{-1} A)^{-1} A^T Q_y^{-1} \underline{y} \\ Q_{\hat{x}} &= (A^T Q_y^{-1} A)^{-1} \end{aligned} \quad (2)$$

Measurements can never be perfect because of limitations to the measurement equipment, point identification and influences from the surroundings exist. Therefore the measurements have variances and co-variances between measurements may exist.  $Q_{\hat{x}}$  gives the precision of the unknown parameters in (2).

Besides computing unknown parameters it is also possible to write down *condition equations* that the observations have to fulfil. An example of a condition equation is the condition that the sum of three corners in a triangle sums up too 200 gon (or 180 degrees). The number of condition equations that can be formed are  $b=m-n$  if the assumptions described earlier are fulfilled.

Combinations of the model of observation equations and the model of condition equations exist; these models are called *mixed models*. An example of a situation in

which a mixed model can be used is when control measurements are available. For example if a house is modelled from total station measurements a condition can be given that walls have to be perpendicular.

To test if the assumptions taken to make the mathematical model that is chosen fits the measurements a testing procedure is performed. The *global test* checks if the model chosen under the null-hypothesis  $H_0$  is a correct description of reality. The global test is computed by (Teunissen, 2000b):

$$\begin{aligned} T_b &= \hat{\underline{e}}^T Q_y^{-1} \hat{\underline{e}} \\ \hat{\underline{e}} &= \underline{y} - A\hat{\underline{x}} \end{aligned} \quad (3)$$

If the global test is larger than a critical value, which is determined by redundancy  $b$  and a threshold  $\alpha$ , the null-hypothesis is rejected.

If the null hypothesis is rejected the mathematical model under the null hypothesis is tested against a alternative hypothesis,  $H_a$ .  $H_a$  specifies possible errors in the measurements or in the mathematical model,  $H_a$  usually can be specified as a linear extension of  $H_0$ . Using the model of (1) the extension will be:

$$H_a : E\{\underline{y}\} = A\underline{x} + C_y \nabla ; D\{\underline{y}\} = Q_y \quad (4)$$

with:

$C_y$        $m \times q$  specification of supposed model error  
 $\nabla$        $q \times 1$  vector with possible model error,  $\nabla \neq 0$

Please note that  $1 \leq q \leq b$ . In surveying it is common to suppose an error in one measurement, this makes the alternative hypothesis one dimensional ( $q=1$ ). In the one dimensional case  $C$  reduces to a vector and  $\nabla$  to a scalar. The test that can be computed from the mathematical model in (1) is:

$$T_q = \hat{\underline{e}}^T Q_y^{-1} C_q [C_q^T Q_y^{-1} Q_e Q_y^{-1} C_q] C_q^T Q_y^{-1} \hat{\underline{e}} \quad (5)$$

With this the test of (5) it is possible to see if the model extension of (4) is significant. In the one dimensional case this reduces to:

$$\underline{w}_i = c_i^T Q_y^{-1} \hat{\underline{e}} / [c_i^T Q_y^{-1} Q_e Q_y^{-1} c_i]^{1/2} \quad (6)$$

The index  $i$  refers to observation  $i$ , if the one dimensional test  $w_i$  exceeds a threshold, called the *critical value*, this measurement is rejected in favour of the alternative hypothesis. The supposed error can now be adapted to the measurement, but more preferably in the case of redundancy the measurement is thrown away.

It is important to understand that the conclusions based on the testing procedure can never be 100% sure. Figure 2 gives the relationship between the null hypothesis and the alternative hypothesis.

Two types of mistakes can be made:

1. Reject  $H_0$  while in fact it is correct
2. Accept  $H_0$  while in fact it is wrong

The possibilities of occurrences of these mistakes should be made as small as possible. The probability of occurrence of

an error of type 1 is called the *confidence level*, if the confidence level is smaller the probability of occurrence of an error of type 2 becomes larger as can be seen in figure 2. The methods described above make it possible to do this, the described method is often referred to as 'Delft School of Geodesy'.

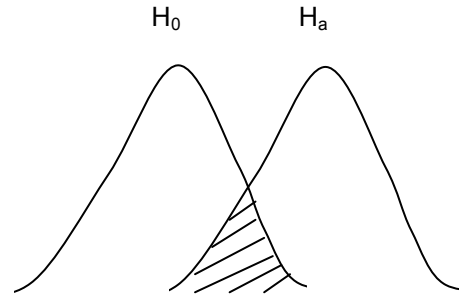
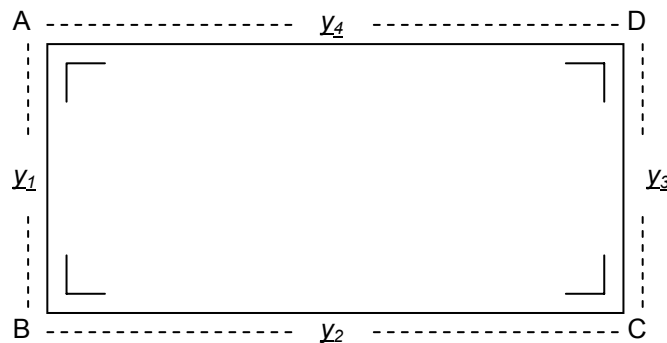


Figure 2: Relationship between  $H_0$  and  $H_a$

*Example:*

Let's consider the survey of a simple house. The house has a rectangular shape and all four walls are measured. Since the shape of the house is rectangular, it can be assumed that the parallel walls have the same length.



The measurements off the walls are  $y_1 = 5.643 \text{ m}$ ,  $y_2 = 10.863 \text{ m}$ ,  $y_3 = 5.645 \text{ m}$ ,  $y_4 = 10.764 \text{ m}$  and have precision  $\sigma = 1 \text{ cm}$ . and are uncorrelated. The model of observation equations can be written down as follows:

$$E \begin{pmatrix} \underline{y_1} \\ \underline{y_2} \\ \underline{y_3} \\ \underline{y_4} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \quad ; \quad Q = \sigma^2 I_4$$



where  $x_1$  is the unknown length of AB and CD, and  $x_2$  is the unknown length of BC and DA. From equation 2 the unknown lengths can be calculated as follows:

$$\begin{pmatrix} \hat{x}_1 \\ \hat{x}_2 \end{pmatrix} = \left( \begin{pmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{pmatrix} I_4 \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \end{pmatrix} \right)^{-1} \begin{pmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{pmatrix} \begin{pmatrix} 5.643 \\ 10.863 \\ 5.645 \\ 10.764 \end{pmatrix} = \begin{pmatrix} 5.644 \\ 10.814 \end{pmatrix}^m$$

$$Q_x = \left( \begin{pmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{pmatrix} I_4 \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \end{pmatrix} \right)^{-1} = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix}$$

Let's consider the alternative hypothesis that one of the measurements has an error.  $c$  in formula ... will then be respectively.  $c_1=(1 \ 0 \ 0 \ 0)^T$ ,  $c_2=(0 \ 1 \ 0 \ 0)^T$ ,  $c_3=(0 \ 0 \ 1 \ 0)^T$ ,  $c_4=(0 \ 0 \ 0 \ 1)^T$ . Before we can compute the w-test, first  $\hat{e}$  and  $Q_e$  have to be computed:

$$\hat{e} = y - A\hat{x} = \begin{pmatrix} -0.001 \\ 0.049 \\ 0.001 \\ -0.050 \end{pmatrix}$$

$$Q_e = I_4 - \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \end{pmatrix} \left\{ \begin{pmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{pmatrix} I_4 \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \end{pmatrix} \right\}^{-1} \begin{pmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{pmatrix} = \frac{1}{2} \begin{pmatrix} 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \\ -1 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 \end{pmatrix}$$

The corresponding values for  $w$  in formula 6 can then be computed:

$$\underline{w}_1 = \frac{(1 \ 0 \ 0 \ 0)I_4 \begin{pmatrix} -0.001 \\ 0.049 \\ 0.001 \\ -0.050 \end{pmatrix}}{\sqrt{(1 \ 0 \ 0 \ 0)I_4 \frac{1}{2} \begin{pmatrix} 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \\ -1 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 \end{pmatrix} I_4 \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix}}} = -0.14$$

$$\underline{w}_2 = 7.00$$

$$\underline{w}_3 = 0.14$$

$$\underline{w}_4 = -7.00$$

For a confidence level of 0.001 that an error of type 1 is made and a probability 80% that there is not an error of type 2 the threshold for the critical value is 2.58, so it is exceeded by  $w_2$  and  $w_4$ . Measurements 1 and 3 are accepted but an error is detected in measurement 1 or 2. Unfortunately there is not enough redundancy to identify the wrong measurement. The only solution is to measure both walls again. The new measurements can either be tested independent from the old measurements, or can be added to the existing model of observation equations.

*End of example*

### MOVE3

MOVE3 is described in a Grontmij Geo Informatie product sheet (*Grontmij, ?*) as: a software package for the design, adjustment and quality control of 3D, 2D and 1D geodetic networks in compliance with the procedures of the "Delft School of Geodesy".

It is important for a surveyor to be able control the quality of his work, because (*Grontmij, ?*):

- Certain quality requirements are given for the work beforehand, it is important to be able to check whether these requirements are fulfilled.
- If the requirements are not fulfilled, due to weak network design or measurements errors, the surveyor needs to know what has to be done extra in order to fulfil the requirements.

The Delft approach consists of calculation methods for the surveyor to be able to check the quality requirements and identify the source of the problems. MOVE3 is a software program that can do these calculations for the surveyor and present the results of these computations. The two quality requirements described above are not only important for the surveyor but also for the GIS users who need quality information for their spatial analysis. Therefore MOVE3 is implemented in the extension *Survey Analyst* in the *ArcGIS* software family. Besides that MOVE3 is also implemented in other programs as Leica SkiPro and Grontmij dgDIALOG Topografie.

Besides the calculation methods of the Delft approach *MOVE3* also makes it possible to import data from survey projects. Not only instruments readings can be important but also comments on these measurements. Examples of these comments are an offset in distance or reflector height.

#### 4. Survey Analyst concept

ESRI describes *Survey Analyst* as an extension of *ArcGIS* that allows one to manage survey data in a geo-database and display survey measurements and observations on a map (*ESRI, 2003*). Displaying geo-data is of course one of the key tasks of a GIS package. Managing survey data in a geo-database is something different. The concept of the data management in a geo-database is shown in figure 3.

The survey data model, which is developed by ESRI Inc. and Leica, is based on four data types: Computations, coordinates, measurements and survey points (*ESRI, 2003, Leica, 2003*). The measurements are the observed data; they can be separated in simple measurements and composite measurements. Simple measurements for example are the observations from a setup point to an object point. Composite measurements can be the group of simple measurements from a setup point that are related and dependent on one or more measurements in that group. The computations give the mathematical relationship between the measurements and the coordinates. Survey points are points in the geo-database that are observed through various surveys. The coordinates define a position on the earth's surface in a certain coordinate system. A survey point can have many coordinates; they can be calculated from several surveys or given coordinates. The survey point is the link between the survey data and the GIS data. One of the coordinates or a weighted mean of the coordinates of the survey point is the coordinate of the GIS-point in the geo-database. When a new survey information is added to the geo-database, the GIS-coordinate of a survey point might change.

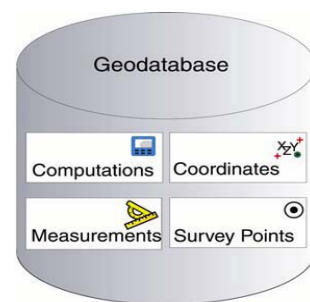


Figure 3: Data management  
In geo-database  
(ESRI, 2003)

The GIS-coordinate is the key-part in the data structure. The GIS-coordinate can be linked with a point of a GIS object in the geo-database. Figure 4 gives the relations between GIS-points, computations, coordinates, measurements and survey points.

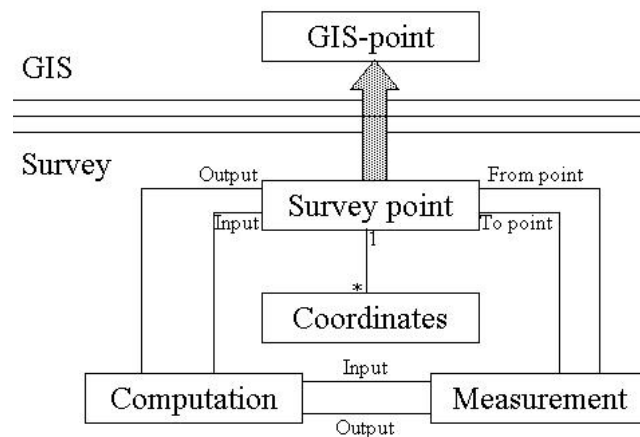


Figure 4: Relations in the geo-database

The survey points are used to describe the survey aware features in the Geo-database, these survey aware features are the same as normal features in the database but are created from GIS-points that are survey aware in the database (ESRI, 2003, Leica, 2003).

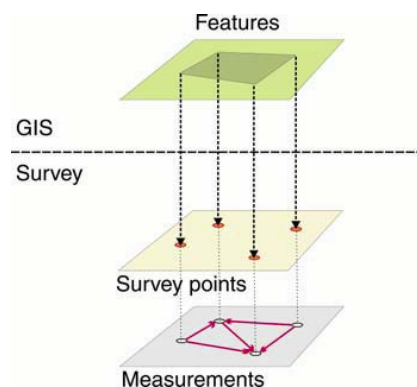


Figure 5: Relation between features, survey points and measurements (ESRI, 2003)

If the coordinates of the survey points have changed they will not be the same anymore as the coordinates of the GIS point. It is now possible to see the link between the GIS-coordinate and the survey point coordinate. If the GIS-points are update the geometry of the selected feature will change.

The storage of measurements is a new development in both GIS and surveying. Usually only computed coordinates and their quality are stored. The coordinates or maps in shape format are output for surveyors and input for GIS-users. Measurements can be added, updated or deleted for new computations and quality information can directly be computed from measurements. Features in other datasets can be snapped and or linked to the survey points in the database. These possibilities arise through the storage of measurements in the

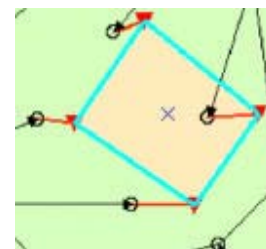


Figure 6: Survey points can be linked to GIS points (Leica, 2003)

geo-database. The data model used to store the measurements is not described here but for the interested reader, more information can be found in ESRI Technical paper: ArcGIS Survey Analyst (ESRI, 2002a). The quality of coordinates is usually different each time it is computed from a different survey project. The storage of old measurements, computations and coordinates make it possible to see these differences and make a choice between coordinates or for example visualise changes.

Several tools are available in *Survey Analyst* to obtain coordinates from survey measurements. They can be separated in two types, coordinate geometry (COGO) measurements and Total Positioning System (TPS) measurements. The following tools exist (ESRI, 2002b):

- COGO
  - Simple computations
    - Enter coordinates
    - Delta XY: Compute coordinates from a known difference to a known point
    - Direction Distance: Compute coordinates from an existing coordinate using known distance and direction values
    - Deflection-Angle –Distance: Compute coordinates by defining a deflection angle offset, based on a reference direction and a known distance from a known point
  - Intersection computations
    - Intersect two distances, a direction and a distance or two directions
  - Circular curve computations
    - Create circles with different parameters s input
  - Station and offset computation
    - Compute points using a sequence of distances and orthogonal offsets from a line or a circular curve
  - COGO traverse
    - Compute a sequence of points starting from an initially known point using direction distance, circular curve or deflection angle computations
- TPS
  - Tachometry: A single instrument is setup at a point with known coordinates. Measured points are calculated from horizontal angle and distance observations
  - Free station: An instrument is setup at an unknown points. Horizontal angle and distance measurements to at least two reference points are used to compute the instruments position and coordinates of measured points
  - Traverse: A sequence of instrument setups that starts at a known location and ends at a known location, with unknown setup points for intermediate points. The misclosure on the end point is distributed over the intermediate points.

- Resection: An instrument is setup at unknown point. The coordinates of the unknown points are computed from horizontal angles to at least three reference points.
- Least-squares adjustment: Several instrument setups are processed with least-squares adjustment techniques described in section 2

These tools make it possible to model objects measurements in the real world. One of the possibilities is the least square adjustment of measurements. The results of the least squares adjustments are also directly tested with the testing procedures described in section 3. The precision of computed coordinates is also a result of the least squares adjustment when this method is chosen. If a different tool is chosen the precision of the coordinates is based on propagation laws that suit the chosen method. Please note that least squares is the only available method in *Survey Analyst* that works with redundancy, so this is the only method where testing is possible. The necessary computations for the least squares adjustment are based on the *MOVE3* software described earlier in section 3.

## 5. Case: Reconstruct objects from a survey project

From the sections described earlier it should be clear what possibilities the GIS package with integrated network adjustment software should offer. To test these possibilities a case was performed using *Survey Analyst*. The case used is an example from the Dutch HTW'96 (*Polman and Salzmann, 1996*). The HTW'96 gives guidelines for surveyors how to perform surveys. Grontmij originally made the case as an exercise for *MOVE3*. The situation is shown in figure 7.

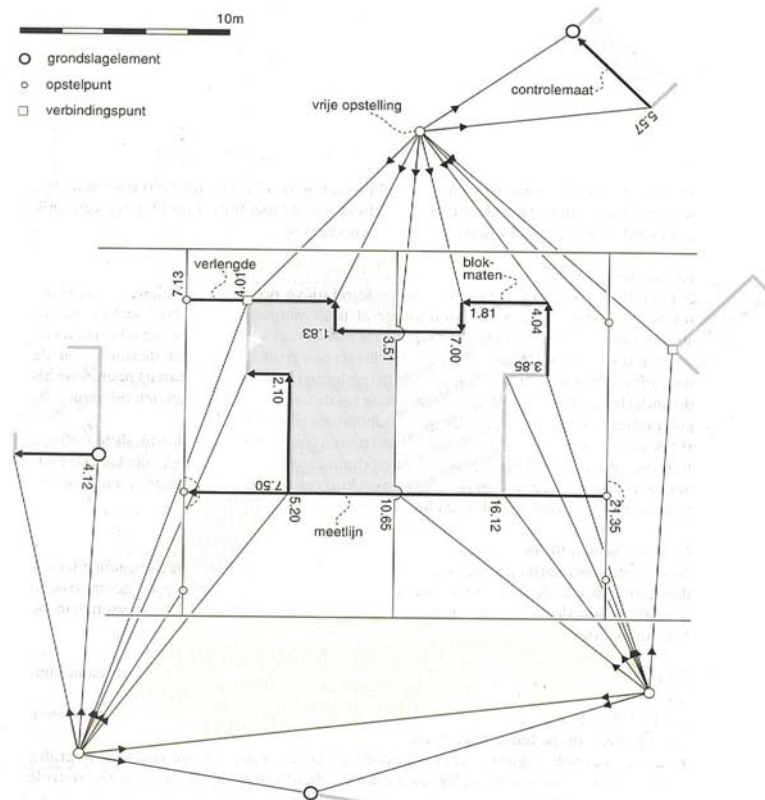


Figure 7: Example of survey project setup (*Polman and Salzmann, 1996 p 352*)

Several types of measurements are available, angles, distances, and relations between lines. The data was imported into a survey project of *Survey Analyst* from a .gsi file, which is the format of Leica instruments. The .gsi format was originally developed by Wild instruments and is defined as: The WILD Geo Serial Interface (GSI) is a general purpose serial data interface for the communication between the different WILD instruments and the communication between WILD instruments and a computer (WILD, ?). A .gsi file looks as follows:

```
*410000+00000000000000001 42....+000000000000T_2      43....+0000000000000000 44....+0000000000000000
45....+0000000000001027
*410000+00000000000000004 42....+0000000000000000
*110001+00000000000000V_1      21.302+0000000000000000      22.302+00000000010000000 31.300+0000000000170400
*110001+00000000000001014      21.302+00000000038245820 22.302+00000000010000000 31.300+0000000000178900
*110001+00000000000001007      21.302+00000000037562360 22.302+00000000010000000 31.300+0000000000184600
*110001+00000000000001004      21.302+00000000036242010 22.302+00000000010000000 31.300+0000000000116000
*110001+00000000000001003      21.302+00000000034223940 22.302+00000000010000000 31.300+0000000000151200
*110001+0000000000000T_1      21.302+00000000029155240 22.302+00000000010000000 31.300+0000000000270730
*110001+0000000000000G_1      21.302+00000000027804890 22.302+00000000010000000 31.300+0000000000177200
*110001+0000000000001027      21.302+00000000038938960 22.302+00000000010000000 31.300+0000000000060300
```

The first three lines with codes starting with 4 give the indication which setup station is chosen (T\_2), what was the last measured point from this setup point (1027).

```
*410000+00000000000000001 42....+000000000000T_2      43....+0000000000000000
44....+0000000000000000 45....+0000000000001027
*410000+00000000000000004 42....+0000000000000000
```

The lines starting with 110001 give the measured points, 21 indicates a horizontal angle 302 indicates that the unit of the measured angel is gon, 22 indicates an vertical angle 31 indicates a horizontal distance 300 indicates that the measured distances is in meters with 4 decimals. So the first measured point is V\_1, horizontal angle 0 gon, vertical angle 100 gon (0 gon is up, 100 gon is in a horizontal plane) and distance 17.04 meters.

```
*110001+0000000000000V_1      21.302+0000000000000000      22.302+00000000010000000
31.300+0000000000170400
```

All setup points are stored in this data format as a .gsi file. The data can be imported via a wizard in Survey Analyst. The data is now stored in the geo-database and is stored as follows in table 1 and visualized in figure 8:

SDB_5_TPSMeasurement : Table									
SDB_OID	SDB_LatestMod	SDB_SurveyID	SDB_SHAPE	HAngle	VAngle	SlopeDistance	RodHeight	HAngleType	VAngleType
9	36	1	.ong binary data	0	100	17.04	0	1	2
10	37	1	.ong binary data	382.4582	100	17.89	0	1	2
11	38	1	.ong binary data	375.6236	100	18.46	0	1	2
12	39	1	.ong binary data	362.4201	100	11.6	0	1	2
13	40	1	.ong binary data	342.2394	100	15.12	0	1	2
14	41	1	.ong binary data	291.5524	100	27.073	0	1	2
15	42	1	.ong binary data	278.0489	100	17.72	0	1	2
16	43	1	.ong binary data	389.3896	100	6.03	0	1	2

Table 1: TPS measurements are stored in the geo-database

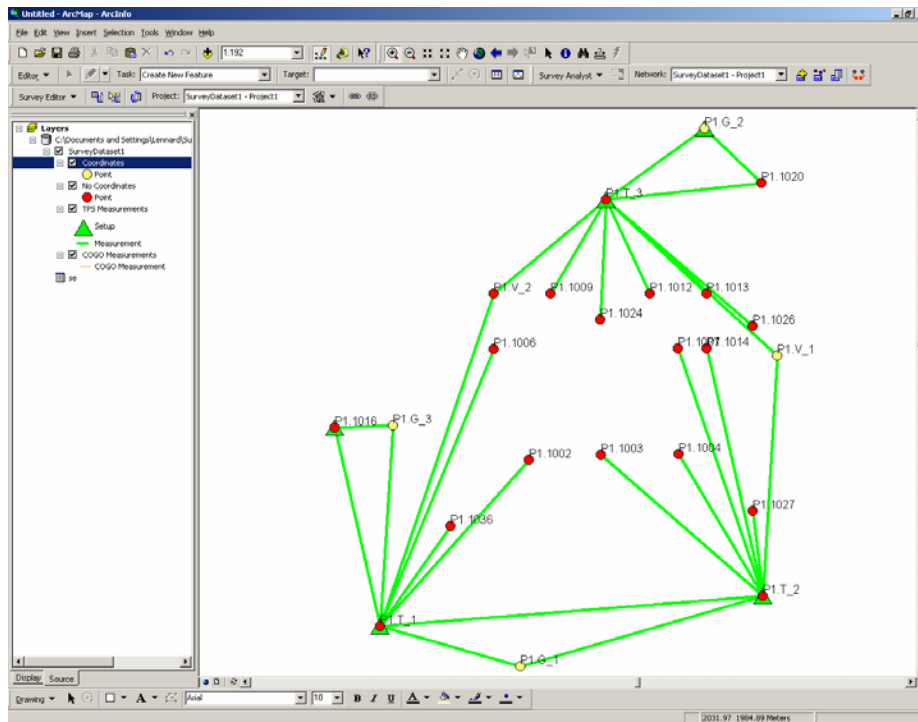


Figure 8: Visualization of Survey Project

The points shown in figure 8 are approximate coordinates, derived through simple computations. By performing a free network adjustment the measurements are controlled. In a free network adjustment the measurements are not connected to the reference points, only the geometry of the measured network is controlled. In this case there is one group of measurements and all of them have to be controlled in the free network adjustment.

A least squares adjustment starts in Survey Analyst by entering the precisions of the different measurement parameters of the network. Also the test parameters that define the critical values for the testing procedure have to be given

Figure 9: Enter precision and test parameters values for least squares estimation

Setup Point	Setup
1 P1.G_2	G_2 / 1
2 P1.T_3	T_3 / 1
3 P1.SP1	

Property	Value
Setup Point	P1.SP1
Setup Name	
Instrument Height	
Date	
Comment	

Figure 10: Enter setup points for least squares estimation



The next step is to define the setup points of the survey project. These points can be given manually or they can be snapped to in the ArcMap window. If a setup point is chosen its measurements become available in the next step. The measurements that have to be used and tested in the least squares adjustment can now be selected from a list. The list is generated from the geo-database.

Point Name	Height	Distance	Azimuth	Zenith
1 P1.G_2	T_3 / 1	100m	Clockwise	Zenit
2 P1.1020	T_3 / 1	100m	Clockwise	Zenit
3 P1.1026	85.0519g	100.0000g	13.710m	0.000m
4 P1.V_1	86.7551g	100.0000g	16.250m	0.000m
5 P1.1013	87.2760g	100.0000g	9.770m	0.000m
6 P1.1012	111.7106g	100.0000g	7.350m	0.000m
7 P1.1024	142.3371g	100.0000g	8.489m	0.000m
8 P1.1009	173.1819g	100.0000g	7.700m	0.000m
9 P1.V_2	194.9441g	100.0000g	10.350m	0.000m

Figure 11: View measurements taken at setup points

Point Name	Fixed Type	Easting	Northing	Elevation
1 P1.G_2	3D	2018.000m	2023.000m	0
2 P1.V_1	3D	2023.150m	2006.950m	0
3 P1.G_3	3D	1996.000m	2002.000m	0
4 P1.G_1	3D	2005.000m	1985.000m	0

Figure 12: Select reference points for least squares estimation

Once the measurements have been selected the reference points and the type of adjustment has to be chosen. When this is done there is enough information available to perform the adjustment and it can be computed. In the given exercise errors are generated that have to be removed from the data by the user. The adjustment shows that the measurement from point T1 to T2 is rejected. There is an error in its slope distance. The measurement can be disabled and the adjustment is computed again. The adjustment is now accepted and the results can be shown and printed in a report.

To Point	Est. Error Hz	Est. Error V	Est. Error Slop...	HsAngle	VAngle
1 P1.1002			0.084m	376.7382g	

Figure 13: View and disable rejected measurements

Point Name	Easting	Northing	Elevation	Std. Dev. P...	Std. Dev.
1 P1.T_1	1994.998m	1988.002m	0.000m	0.011m	0
2 P1.1002	2005.939m	1999.335m	0.000m	0.022m	0
3 P1.1006	2003.101m	2007.501m	0.000m	0.027m	0
4 P1.V_2	2003.128m	2011.407m	0.000m	0.029m	0
5 P1.1016	1991.880m	2002.003m	0.000m	0.026m	0
6 P1.1036	1999.999m	1995.001m	0.000m	0.020m	0
7 P1.T_2	2022.005m	1989.999m	0.000m	0.027m	0
8 P1.1014	2018.158m	2007.475m	0.000m	0.036m	0
9 P1.1007	2016.126m	2007.503m	0.000m	0.035m	0
10 P1.1004	2016.125m	2000.002m	0.000m	0.030m	0
11 P1.1003	2010.659m	1999.998m	0.000m	0.027m	0
12 P1.1027	2021.356m	1995.995m	0.000m	0.032m	0
13 P1.T_3	2011.072m	2018.045m	0.000m	0.040m	0
14 P1.1020	2022.063m	2019.114m	0.000m	0.051m	0

Figure 14: Results of accepted least squares adjustment

The adjustment was also performed in *MOVE3*. The results of the computation of *Survey Analyst* were the same as the results of *MOVE3*, but the presentation and procedure were different. *MOVE3* for example gives a graphical representation of the measurements that are rejected. If there is a visualization of the results it is easier, for a surveyor, to interpret the type of error. This is important because an error in a measurements may affect the test results of other measurement as well so that they are rejected to.

Since the free network adjustment has been accepted it is assumed that there are no errors in the measurements that can be tested. The next step is to connect the measured point to the existing coordinate system and reference points. So instead of a free network adjustment a constrained adjustment is performed. This adjustment controls the reference points and computes coordinates for the measured points. The adjustment was rejected by *Survey Analyst*, but it did not become clear why it was rejected. A lot of measurements were rejected, but the actual problem was the given coordinates of point V\_1. From *MOVE3* this became very clear in a list of rejected items with the most probable error on top:

No.	Type	Test	Factor	F.	To
1	Coordinate	T-test (2)	2.1	V_1	
2	Coordinate	V-test	2.0	G_2	
3	Distance	W-test	1.8	T_1	V_2
4	Distance	W-test	1.8	T_3	V_1
5	Distance	W-test	1.5	T_3	G_2
6	Direction	V-test	1.3	T_3	V_2
7	Distance	W-test	1.2	T_3	V_2

Figure 15: List of rejected items in *MOVE3*

The manual of *Survey Analyst* describes that emphasis of the constrained adjustment is on testing the reference points as well as computing final coordinates (ESRI, 2002a), but it does not give an indication of possible errors in reference points. Point V\_1 was removed as a reference point and the adjustment was accepted and new coordinates for V\_1 and all other points were computed.

So far only the TPS measurements have been used to compute coordinates with a least squares adjustment. The testing procedure only tested points that could be tested. The TPS measurements do not provide enough information to control all points, so extra information is added from conditions and relations like straight lines, perpendicular lines and steel tape measurements. These measurements can not be added as TPS measurements in *Survey Analyst*, but COGO measurements offer a solution to add the available conditions and relations, although a few were transformed to be able to add them as a COGO measurement.

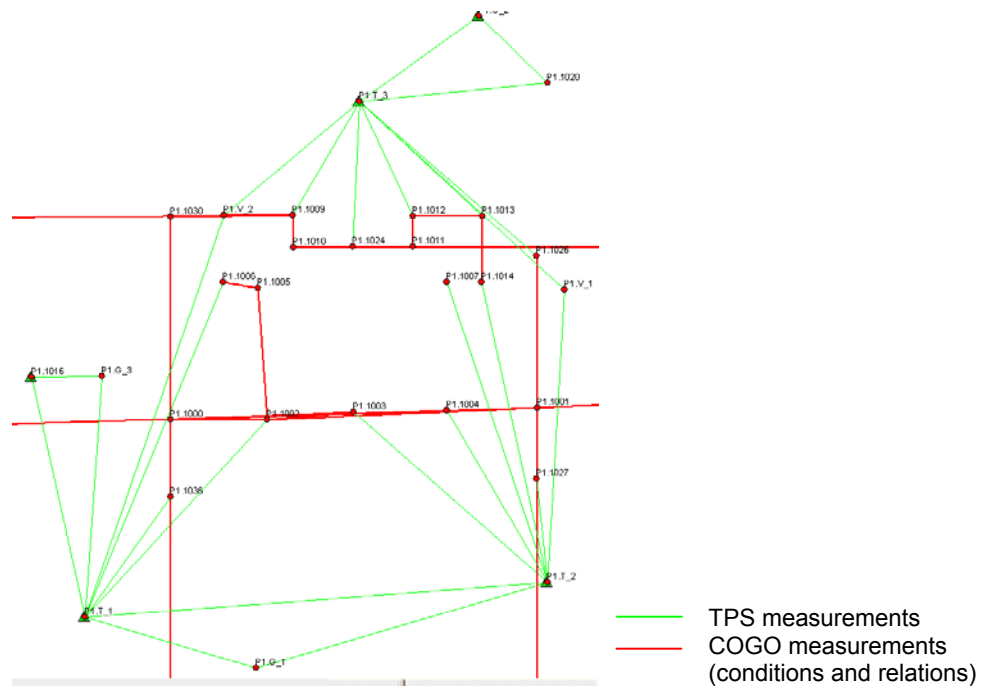


Figure 16: Conditions and relations added to survey project

The information added by conditions and relations can contain errors and errors in measurements that are now controlled can be detected. Therefore the conditions and relations have to be added to the least-squares adjustment as well. Unfortunately this is not possible in *Survey Analyst*. It is possible in *MOVE3* and the adjustment in *MOVE3* gave an error in the direction from T\_1 to 1002 and in the measures distance of 1012-1013. These errors were described in the exercise as errors in writing down numbers, eg. the distance written down between 1012-1013 was 4.40 meters but it should be 4.04 meters. The errors were corrected and the result of performing this exercise is shown in figure 17.

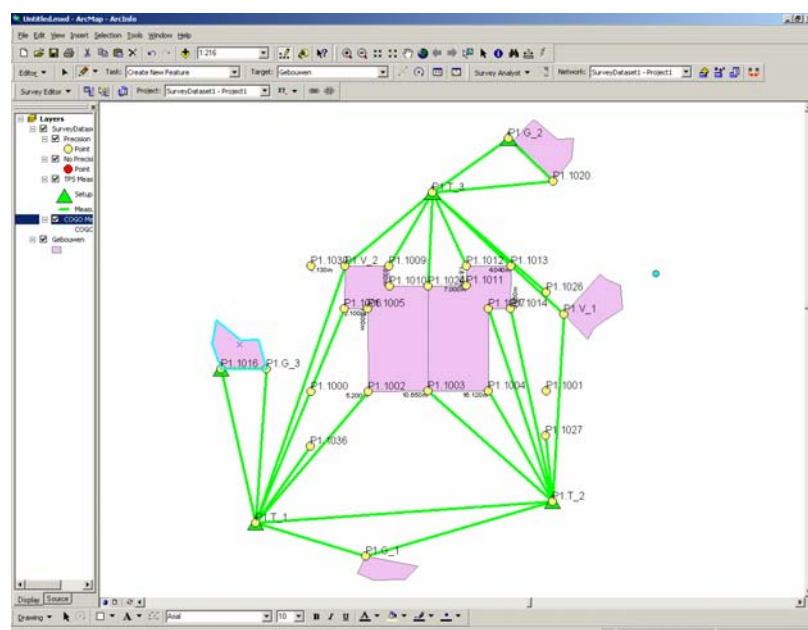


Figure 17: Building reconstructed from survey project

Unfortunately the buildings could not be directly reconstructed from the available information in the survey projects. The buildings could easily be reconstructed by connecting the survey points.

The building has now been constructed in a GIS package without the use of other software. All information on the construction is therefore still available and can be looked at. All computations that led to a points coordinate are available and can be looked up. Besides coordinate information quality information is easily accessible for points.

The screenshot shows a software window titled "Survey Explorer | Points [XY-Point 1]". It contains a table with columns: Type, Object Name, Project, and Name. A context menu is open over the table, showing options: "Go To Computations", "Go To Survey Points", "Go To Measurements", "Export Survey Points...", and "Go To Details".

	Type	Object Name	Project	Name
1	XY-Point	P1.V_1	Project1	V_1
2	XY-Point	P1.G_1	Project1	G_1
8	XY-Point	P1.V_2	Project1	V_2
9	XY-Point	P1.1016	Project1	1016
10	XY-Point	P1.1036	Project1	1036
11	XY-Point	P1.T_1	Project1	T_1
12	XY-Point	P1.1014	Project1	1014
13	XY-Point	P1.1007	Project1	1007
14	XY-Point	P1.1004	Project1	1004

Object 1 of 23

Figure 18: View survey points and computations

The screenshot shows a detailed table of survey points with columns: Type, Object Name, Project, Name, Easting, Northing, Elevation, MD, Qxx, Qyy, Qxz, Qyx, Qyz, Qzx. The table contains 18 rows of data.

	Type	Object Name	Project	Name	Easting	Northing	Elevation	MD	Qxx	Qyy	Qxz	Qyx	Qyz	Qzx
5	XY-Point	P1.T_2	Project1	T_2	6633.8511R	6528.9309R	0.000R	1	2.411973456...	2.948314221...	-6.992376145...	2.938417954...	-2.902769958...	1.297321...
6	XY-Point	P1.1002	Project1	1002	6580.0417R	6559.9261R	0.000R	1	2.487569563...	6.822284876...	4.584362728...	1.693187904...	6.734607198...	1.016404...
7	XY-Point	P1.1006	Project1	1006	6571.7705R	6586.1544R	0.000R	1	4.354248088...	1.035200454...	8.493222196...	1.158934833...	2.044511207...	2.582255...
8	XY-Point	P1.V_2	Project1	V_2	6571.8246R	6598.9378R	0.000R	1	2.824322291...	6.399263961...	-2.549598694...	1.109903952...	-8.689553681...	5.322476...
9	XY-Point	P1.1016	Project1	1016	6535.0284R	6568.0924R	0.000R	1	6.506479475...	-6.902985249...	8.504830912...	1.186469911...	-2.074986621...	2.394123...
10	XY-Point	P1.1036	Project1	1036	6561.6784R	6545.1897R	0.000R	1	4.153701813...	3.922024390...	5.204911185...	1.897812467...	-1.564463862...	6.065449...
11	XY-Point	P1.T_1	Project1	T_1	6545.3057R	6522.2523R	0.000R	1	2.288613047...	-8.101408576...	1.295167909...	1.543874331...	-2.594043260...	3.783037...
12	XY-Point	P1.1014	Project1	1014	6621.1152R	6586.1769R	0.000R	1	2.363053477...	-3.660631196...	5.195323596...	6.972901679...	-1.271599016...	1.812543...
13	XY-Point	P1.1007	Project1	1007	6614.4550R	6586.2492R	0.000R	1	2.368928106...	-4.532374404...	4.983403001...	8.600549573...	-1.632948312...	1.881331...
14	XY-Point	P1.1004	Project1	1004	6614.5214R	6561.6717R	0.000R	1	2.172662217...	-8.429514259...	3.853156717...	1.438687943...	-1.126618288...	1.027213...
15	XY-Point	P1.1003	Project1	1003	6596.5936R	6561.4025R	0.000R	1	2.091695314...	-1.092392713...	4.137247879...	1.843544828...	-2.178202641...	1.086151...
16	XY-Point	P1.1027	Project1	1027	6631.6940R	6548.5807R	0.000R	1	3.335640872...	-1.113447788...	2.106436571...	1.719054582...	-1.656066482...	1.304141...
17	XY-Point	P1.1020	Project1	1020	6633.7897R	6624.3669R	0.000R	1	3.475739828...	3.796882587...	7.936201554...	1.640419569...	5.716546644...	1.093756...
18	XY-Point	P1.1026	Project1	1026	6631.6812R	6591.2412R	0.000R	1	1.017773532...	-7.866958909...	-1.902011712...	1.504476594...	1.675695735...	9.676519...

Object 1 of 23

Figure 19: Coordinate and quality information is available

The buildings that were created from the survey points have information available on its length and area of its shape. The area and length are calculated from the coordinates of the points, the size of the area in the database is easily checked with formula 7 (Alberda, 1994).

$$Area = \frac{1}{2} \sum_{i=1}^n x_i (y_{i-1} - y_{i+1}) \quad (7)$$

where the sum is circular, i.e.  $(x_0, y_0) = (x_n, y_n)$

OBJECTID*	SHAPE*	SHAPE_Length	SHAPE_Area
1	Polygon	37.453350	64.377523
2	Polygon	37.751288	63.756478
4	Polygon	23.740801	23.858813
5	Polygon	25.748933	31.317894
6	Polygon	18.147804	18.165396
7	Polygon	15.850972	14.167974

Record: 1 Show: All Selected Records: (1 out of 6 Selected.)

Figure 20: Shape, length and area information of constructed objects

Quality information of the survey points is available in the database but is not used to give an indication of the quality of the calculated area and length of the shape. It can easily be computed when applying the propagation law for variances (*Polman and Salzmann, 1996*) to formula (7). The propagation law for variances is given as:

$$Q_u = U Q_x U^T$$

with  $\underline{u} = U \underline{x}$

(8)

If the propagation law for variances is applied to formula (7) a complex formula is created. For a computer, however it is easy to compute this formula. It is easy to implement a routine to give information on quality of calculated values, because formulas exist to do so. Although quality information is one of the main reasons to implement survey data and adjustment software in a GIS package the available information is, not yet, used for GIS operations.

This case shows the possibilities and limitations of constructing new features from a survey project compared to a common used tool as *MOVE3*.

## 6. Conclusions

ArcGIS Survey Analyst is an extension of ArcGIS that enables the user to integrate GIS and surveying in one software package. The Survey Analyst extension is user friendly, especially if one has experience with ArcGIS software. Basic functions like traverse and least squares adjustment and testing are implemented in the package. The stored data is easy to access and analyse.

Not all functionality one might expect in such a software package are implemented (yet ?). Especially from a surveying point of view the possibility to add control measurements and condition properties to the least squares adjustment should be added, also information added to measurements in the field like *this is a line* should be able to be imported. A feature like this makes reconstructing of objects easier.

Two problems with the feedback of the measurements that are rejected when the null-hypothesis is rejected in the least squares adjustment and testing procedure

came across in a case. The first problem was that no graphical representation was given of the rejected measurements. Visualisation of the rejected measurements makes it easier to interpret the type of error that might have occurred in the survey project. A second problem that came across is that only rejected measurements in direction and distance were reported in the report of the adjustment. It is however also possible that coordinates of reference points are rejected in the testing procedure; these rejected measurements are not reported in *Survey Analyst*. If a rejected item is not reported it will also not be adapted or removed by the user. The testing of reference points is the emphasis of the constrained adjustment that is a part of *Survey Analyst*. The null-hypothesis will not be accepted as long as redundant information is available to control the measurements that have an error. The *MOVE3* software that is implemented in *Survey Analyst* to do the least-squares adjustment and testing can report rejected reference points; hence it should be possible for *Survey Analyst* to report them as well.

From a GIS point of view the quality information should directly be given to objects in its tables, if this information can be generated from the survey project. The availability of quality is an important reason why network adjustment software is implemented in GIS software, so it should be available.

Besides adding some functionality to the software the discussion is if this software should be used in office or in the field. *Survey Analyst* is a package that is developed for office use, but lacks some functionality for that purpose. A field application might be a solution to some functionality issues, for example the measured points can be linked directly on a pen computer. A field application gives some problems with data issues, where for an office application and a central geo-database these issues have already been solved. Especially for updating existing information in the database *Survey Analyst* is suitable. Mutations can easily be measured and added to the database if a field application is available.

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