

Constructing a Survey Accurate Digital Cadastre

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ABSTRACT

Land Information New Zealand has contracted EDS to convert historic survey data for the construction a Survey-accurate Digital Cadastre. The areas selected contain 1.35 million parcels, or approximately 70% of the live parcels that constitute the New Zealand survey system.

This work has been undertaken in three parts: the definition of a new datum to which the converted survey will be adjusted; the creation of a sufficient density of control in the conversion areas to gain a high degree of co-ordinate accuracy; and the capture and adjustment of boundary and traverse data from current survey plans tied to the new control. The intent of the exercise is to create a network of a measured co-ordinate accuracy standard that can be used by external surveyors and for electronic plan lodgement.

EDS has developed specialist techniques and tools for the accurate capture and adjustment of the network. Capture of parcel boundaries and traverse is performed for all plans supporting current parcels, with least-squares adjustment performed in terms of the new datum. In order to achieve the required timeframes, the system developed is an automated multi-step production workflow process that is scalable to support a large workforce. All software tools have been developed to perform single specialists functions to support this model. Considerable performance benefits have been realised through this approach.

Management of both the workflow process and the quality processes are vital to the success of the operation. EDS has ensured that quality feedback and iterative quality improvement is an integral part of the process. The “productionisation” of the conversion process has allowed the centre to grow to over 100 staff, producing 8,000 thousand converted parcels per week.

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1. BACKGROUND

Land Information New Zealand (LINZ) commenced a programme in 1996 to automate the nation's survey and title systems. The intent was to create a single, integrated electronic register that maintained the previously paper based information as intelligent records. This vision has been realised in the system *Landonline*, which began processing survey and title transactions in April 2000. (Haanen, Bevin, Sutherland, 2002, at FIG XXII)

As part of the Automation Programme, EDS has been contracted by LINZ to provide the backfile conversion of paper title and survey records to populate *Landonline*. EDS commenced development of the titles and survey conversion solutions in 1999. Title conversion commenced in April 2000. Survey conversion commenced in production in November 2000.

This paper will outline the survey conversion process EDS has implemented, and highlight some of the issues EDS believes are central to the cost effective solution it has adopted in New Zealand.

2. CONVERSION REQUIREMENTS

The objective of the conversion process is to create a Survey-accurate Digital Cadastre using the existing source records, the DCDB, the geodetic control network, and survey plans. The Survey-accurate Digital Cadastre is still an observation based cadastre. However, the calculated coordinates can be used to locate marks and to validate that observations on new surveys are correct. The aim of conversion is to capture and adjust data to maximise the number of nodes that satisfy the accuracy standard specified in the Survey Regulations 1998. Nodes that meet these criteria are given "SDC" status. (Haanen, Bevin, Sutherland, 2002, at FIG XXII)

Conversion must operate concurrently with *Landonline*. To support this, these source records must be extracted from *Landonline* at the time a given area commences conversion to ensure the most up to date record is used.

2.1 Source Data for Conversion

2.1.1 DCDB

The DCDB was limited in accuracy due to the digitising process used in its creation. However it does provide the parcel fabric base against which survey data can be added. LINZ have converted each of the 12 existing databases into *Landonline* format, which form the initial parcel definition to which conversion adds survey data.

2.1.2 Survey Plans

LINZ had previously scanned virtually all of the existing survey plans. This enabled the conversion operation to operate entirely image-based, with reference to source plans or microfilm only where legibility issues exist.

2.1.3 Geodetic Control

Through the Automation Programme, LINZ has created a new datum, NZGD2000 to overcome the shortcomings of the previous datum, NZGD49. This has been implemented through *Landonline*, with all nodes coordinated in terms of it.

The integrity and density of geodetic control is vital to the accuracy of the cadastre created through conversion. As part of the conversion exercise, the density of 5th order control in the conversion areas was assessed, and deficient areas were identified for new control surveys. Within the conversion areas, the vast majority of boundary marks are no more than 200m from a control point in urban areas, 600m in peri-urban areas, and 2km in rural areas.

2.2 Capture Requirements

The boundary bearings and distances are being captured for almost all current parcels. Parcels defined on very old plans may not be captured, as their data are unlikely to meet modern standards. Additional “traverse” bearings and distances are captured to join blocks together (e.g. across roads) and to connect the parcel fabric to the NZGD2000 control, which provides the fixed framework. The aim of including this data is to maximise the geometric strength of the network for adjustment by least squares and the generation of coordinates. The success of this approach in any area is dependent on the fact that individual surveys have been done to a reasonable and consistent accuracy, and that there are good interconnections between surveys.

Least squares adjustments are used to assess compliance with the accuracy requirements contained in the 1998 Survey Regulations (typically a few centimetres in urban areas). The test includes both relative and absolute accuracy tests, treating the geodetic control points as “origin” marks. Each node (mark) is tested, and assigned SDC status if it passes. Nodes that are either poorly connected to the control network or which are fixed by lesser quality (older) observations are unlikely to achieve SDC status. This back-capture of historical data can at best only achieve the standards of those surveys – the survey-accurate cadastre will only be as accurate as the surveys that comprise it.

There is no effort to correct errors in the original record, however these are highlighted for later investigation.

2.3 Selection of Survey Conversion Areas

Analysis by LINZ indicated that in the large rural tracts of New Zealand surveys have tended to be mathematically inconsistent and geometrically weak and conversion would not result in precisions compatible with SDC standards. In addition, the high cost of converting these areas, which are surveyed very infrequently, would far exceed the benefits derived. As the majority of the benefits to LINZ and external users are derived from more efficient survey processing, the areas in which surveys were likely to occur drove the selection criteria. Priority was therefore given to urban, high-density peri-urban, and rural areas containing intensive pattern of parcels or development. Further areas where there had been a large amount of recent survey activity were added.

A total of some 1.35 million (of the country's 2 million) parcels will be converted. Most rural and remote areas that comprise some 90% of the country's area will not be converted.

2.4 Freeze Areas

The conversion exercise is concurrent with normal LINZ business operations. In order to handle new survey processing and conversion simultaneously, restrictions are placed on the activities that can be performed in *Landonline* for areas that are in the process of conversion. This restricts conversion to working on sets of contiguous areas known as *freezes*. In order to simplify the management of these areas for conversion, *Landonline* users, and external surveyors, it was agreed that a new freeze area would only commence conversion over a weekend break.

2.5 Timeframe

EDS has set a timeframe of two and a half years for the total conversion of the selected areas. LINZ had also requested that the duration of conversion of each freeze be as short as possible, and of a reliable duration for each successive freeze, to minimise the impact on external users. This requires the completion on average of over 13,000 parcels weekly, with given areas due for delivery each week.

3. SOLUTION DESIGN

In order to meet the requirements and time constraints for the conversion exercise, it was necessary that any solution have three additional attributes. The process needs to be:

- Segmentable, allowing multiple users to work on adjacent data performing possibly different functions simultaneously;
- Scalable, enabling the target throughput to be achieved by having as large a workforce as necessary; and,
- Automated, so that efficiencies are derived through increasing the scale of the operation rather than increasing the overhead.

One of the constraints on scalability is the availability of potential staff in the marketplace. This is particularly important in New Zealand, as the labour pool of survey professionals is small. In order to deal with this issue, the solution adopted would need to separate as much as possible tasks that can be accomplished by staff with no previous survey experience from those that require a strong survey background.

Taking this approach, the completion of a single parcel takes the coordinated efforts of a numbers of individuals, each of whom provide part of the input to the final completed data. **This makes the coordination and management of work vital to the success of the project as a whole.**

The other constraint on scalability is the software costs for each user station. Cost savings achieved in reducing the overall timeframe for conversion are offset by these costs. EDS took the approach of bespoke development in order to minimise the cost per workstation for additional users.

While there are a number of examples of pilot or proof of concept data conversion of this type, there were no “productionised” examples available at the time the project commenced. The process developed was based instead on EDS’ experience in defining and managing production workflow processes from other industries.

4. THE PRODUCTION PROCESS

The creation of converted data for *Landonline* is performed as a nine-step process. These steps are;

- Regional Planning
- Data download from *Landonline*
- Data Preparation
- Data Capture
- Quality Control
- Network Adjustment and SDC status
- Topology Maintenance
- Quality Assurance
- Upload to *Landonline*.

The data from each step feeds into the next, which builds on that data. Through this process, each step is acting as a quality check for the preceding one, with the accuracy of the data captured being progressively refined.

The solution has been built as an automated workflow management system. This workflow system links each of the specialised tools used to perform the tasks of conversion. Each process step has at least one specialist tool developed to perform that task. **There are 13 specialist tools in all that deliver the functionality of the complete system.**

The tools have been tailored to efficiently achieve the requirements of their process step. All of the tools have been developed and are owned by EDS.

4.1 Regional Planning

As a first step to converting any area, a Survey Capture Area (SCA) definition must be spatially broken down into manageable work units. It is divided into freezes that are sized to be approximately one week's work for each production stage. These are then divided into *blocks*. These are the smallest unit of work managed in the system, and consist of 150 to 200 parcels, bounded where possible by control marks. The spatial definitions of freezes and blocks are used when constructing the working data sets used in conversion. When downloaded, each block contains the parcels' definitions, all plan images, and all geodetic data related to that block.

4.2 Download

Data is extracted from *Landonline* to form the framework on which historic data is to be added. The current data for each parcel is needed, as there may be new *Landonline* surveys or provisional plans that need to be taken into account in the capture and adjustment processes. Once the extraction is completed, the area becomes "frozen" in *Landonline*, and only limited actions may be performed on those parcels pending upload into that system.

4.3 Data Preparation

The preparation phase is where local survey knowledge is applied to assess and plan the work required to process a given freeze. Plans are assessed and parcels excluded from capture where data is unreliable. Any interpretation required, such as calculation of balance distances or specific arc calculations, is also performed. An assessment is of ties required to geodetic control, at intersections and across roads, and to bridge weak areas. These are highlighted on the plan images to form instructions to later stages of the process.

4.4 Data Capture

The capture staff are responsible for the data entry of most of the required data. This includes plan header details, boundary observations, traverse observations, and boundary and traverse mark data. Observation classes are assigned to be used during the adjustment process. Specific quality and consistency checks such as parcel closure calculations are performed by the software tools to highlight simple errors.

4.5 Quality Control

The quality control team use a number of specific tests to identify errors in preparation or data capture of the block, or in the source data. This interpretation requires some survey experience and good problem solving capability. Included in the set of tests is the use of least-squares adjustments to highlight capture errors.

4.6 Network Adjustment

The adjustment process deals with the complete set of source and captured data, with the adjustment also being performed using least squares. Each block is first adjusted to highlight capture errors or inconsistencies in the source data. Capture errors are corrected, while source errors or inconsistencies are either down weighted or excluded from the adjustment. Adjustments are then performed between blocks to derive a consistent result between adjacent areas. Once the final adjustment has been performed, coordinates are derived in terms of NZGD2000. At this point, SDC status is generated for these final adjusted coordinates.

4.7 Topology Maintenance

Parcel topology must be maintained through conversion, with *Landonline* unable to support parcel gaps, overlaps or inversions, or line intersections. The adjusted network is edited to resolve these conflicts prior to data being uploaded to CRS.

4.8 Quality Assurance

LINZ staff work on site to check key aspects of the interpreted data captured, such as part parcels, excluded parcels, and errors identified in the source records. They also check the quality of the final adjustment, assessing down weightings, exclusions and the SDC results.

4.9 Upload to Landonline

Completed blocks are then re-loaded back into *Landonline*. Captured observations, marks and coordinates supersede those that existed for existing lines, and new aspatial and spatial data is created for new observations and marks. The freeze established in *Landonline* is updated automatically with each block loaded.

4.10 Production Cycle

To manage the flow and allocation of work, EDS commences a new freeze each week. The freeze is sized to be approximately one week's work for each team. As a result, the end-to-end time for any given freeze is of the order of five weeks.

Typically, a number of adjoining freezes make up a survey capture area. As the boundary of each freeze will need to be adjusted in relation to its neighbour, this creates delays on the border as one freeze waits for its neighbour's bordering blocks to reach the adjustment process. This process creates a "wave" of completed data moving through each SCA.

5. PRODUCTION MANAGEMENT

Strong production and quality management has proven to be the key to maintaining consistent delivery of converted data.

5.1 Quality Management

Maintenance of high quality levels at each stage of production is vital to minimising rework, and the reliable delivery of data. This has been achieved through;

- Automated quality checks incorporated in the user applications where possible
- Accurate and consistent recording of errors
- Timely feedback to individuals and teams
- Remedial training for individuals and teams
- Accurate statistical trend analysis to anticipate potential quality issues and maintain a programme of continuous improvement

As part of the quality programme, work is assessed and streamed to operators with the required level of expertise. Individual improvement programmes are in place to increase the skill level of each operator to be able to move their performance to higher levels.

5.2 Recruiting and Training

Skilled survey resources are scarce in the New Zealand labour market. The multi-stage process described above was designed in recognition of this, and on the assumption that people from non-survey backgrounds could be trained to perform at the required level. An extensive training programme was developed and has been refined through successive generations of new staff. Based on the performance of staff hired the recruiting policy has been refined to better target non-surveyors with the right skills to learn quickly.

The success of this approach can be seen in the staff mix and the performance of those staff. Only 1/3 of the current production team have survey backgrounds, and yet the overall quality for data captured is well in excess of 99% accuracy.

5.3 Workflow Management

Maintaining sufficient inventory for each process step, and managing the allocation of work to resource based on difficulty can be time consuming and difficult to achieve. As described earlier, the requirement of freezes to commence only on weekends means that there can be no adjustment to the volume of work to be processed to take into account variations in complexity of data or availability of staff.

EDS has developed tools to automate the streaming and allocation of work as much as possible, and to assist in scheduling and contention resolution to deliver the most efficient flow of work through the system.

6. THE OPERATION

Currently the production operation employs over 100 staff. They are split into functional teams performing single process steps. Only the Data Preparation team has a predominance of staff from surveying backgrounds. About half of the adjustment team has a survey

background, while the remaining staff have a variety of backgrounds and have been trained specifically for this project.

The centre is currently producing the following outputs on a typical day;

- Preparation, capture and QC of data from over 600 plans per process step
- Capture of 18,000 boundary observations, or one every 1.4 seconds
- Capture of 2000 traverse observations
- Capture of 7000 marks and their details
- Calculation of 60,000 adjusted coordinates.

Data quality at first time inspection QA is consistently at over 99.6%. Weekly, an average of 8,000 thousand parcels complete the conversion process and are activated in *Landonline*.

The centre is still increasing throughput, and is expected to be producing 15,000 parcels per week by September 2002. The entire conversion project is expected to run until mid 2003.

The accuracy of the source data varies from region to region. However, the approximate number of nodes achieving SDC status is a pleasing 70%. This shows that the existing records, especially new surveys, are ready to support the vision of electronic lodgement and automatic validation of new surveys in *Landonline*.

7. LESSONS LEARNED

Through the development and management of the conversion operation, the team has learnt a number of key lessons.

7.1 Specialist Tools

The development of specialist, tailored tools has provided EDS with considerable advantages over other approaches. There have been substantial performance achievements through the optimisation of code. The tools themselves have supported the approach of hiring and training non-survey staff through the embedding of business rules in the software to minimise the training effort required.

This approach has had the added benefit of achieving a more cost effective solution than one predominantly using commercial GIS tools.

7.2 “Productionisation”

EDS has developed a robust, production ready solution by breaking the survey conversion process into steps and developing processes and software for each step while ensuring that the work in each step adds value to its successor. This is a vital requirement for any large scale operation of this kind.

7.3 Quality Management

Quality management is the key to a successful production operation. Without tightly controlled quality monitoring and feedback to staff it is possible for production issues to escalate to the point where throughput is dramatically affected. However it is not possible to “inspect in” quality to the process, it must be an inherent part of the process by design.

7.4 Least-Squares as a Quality Tool

The conversion process makes extensive use of least squares adjustment techniques to validate the correctness and consistency of data. They provide consistent and reliable methods for identifying and isolating data capture or source data errors.

7.5 Issue Resolution

We have learned that it is not possible for issues requiring resolution to be solved off-site. When issues are found with the source material, holding up that piece of work will cause production scheduling issues, and will delay the capture of related data, leading to an overall bottleneck in the process. The mechanism for on-site resolution needs to be, and was, developed and agreed with LINZ to enable smooth workflow management and to ensure that LINZ is fully committed to the solution arrived at.

8. CONCLUSION

EDS believes that our experience in New Zealand would be of great benefit in other jurisdictions. We have

- Gained a clear understanding of the detailed needs and opportunities inherent in the administration of land information systems.
- Developed a complex and specialised process into a series of component steps which enable the development of a large scale “production” operation.
- Developed a number of specialist software tools that do not use commercial GIS products deliver the functionality and flexibility required with high levels of productivity and cost benefits.
- Ensured quality management is a key factor in maintaining an efficient and reliable production operation, and built quality management into the production process.
- Taken non-survey staff and training them in a reasonable timeframe to perform specific survey interpretation functions to the required standards, thereby reducing costs and overcoming skilled labour shortfalls.

This experience has highlighted that New Zealand was ready for a conversion exercise of this magnitude. LINZ had the right approach in *Landonline* to the development of an integrated electronic survey and title system. Equally importantly, the integrity of the geodetic control network and the quality of the cadastral survey data make the vision of a Survey-accurate Digital Cadastre achievable.

The move from paper based records to intelligent survey records in any jurisdiction is not a matter of “if”, only a matter of “when”. We would welcome the opportunity to be of assistance in a similar way with other land registries.

EDS is very proud to be associated with the far sighted objective of the government in New Zealand to establish intelligent land records and automate transaction processing. We believe LINZ will be very successful in facilitating user friendly and highly interactive systems for all those concerned with the administration of land in New Zealand.

REFERENCES

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BIOGRAPHICAL NOTES

David Spaziani has worked for over 15 years in a variety of design and implementation roles for systems involving business process automation. In 1998 he became the lead architect for the design and implementation of the EDS survey and land title conversion systems. In 2001 he became manager of the survey conversion production team. He holds a Bachelor of Science Honours degree from the University of Melbourne.