INDOT Research

TECHNICAL *Summary*

Technology Transfer and Project Implementation Information

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Modern Technologies for Design Data Collection

Introduction

The need for this research was motivated by the realizations that (1) field data collection is a very time consuming, labor intensive and error prone activity, and that (2) this is a field of frenetic research and development efforts by commercial equipment manufacturers and by academic researchers. A prudent organization would reassess their data collection methods every few years to permit them to take advantage of advances and innovations in the technology.

Particular attention will be paid to issues of database formats, CAD data formats, and other software standards so that any data sets

produced would be compatible with existing analysis tools. Nevertheless, to look ahead, we will suggest some likely candidates for consideration when the decisions are eventually made about which areas of measurement and data collection technology appear to be the most promising.

The project is aiming at intelligent selection and evaluation of recently developed and improved methods to collect or use geospatial data in order to be adopted by the Indiana Department of Transportation (INDOT) for the sake of higher level of efficiency regarding content, accuracy, effort, time and cost.

Findings

The results of this project are as follows:

- 1) A terrestrial Lidar survey provides an efficient and timely tool to generate data for as-built surveys and engineering design.
- 2) The Lidar survey acquired the same accuracy as classical survey data collection methods: aerial photogrammetry in combination with terrestrial surveys.
- 3) The Lidar survey requires careful planning as to the still needed control surveys. Once the control surveys are in place Lidar surveys equal classical survey techniques in accuracy, but outperform them in timeliness.
- 4) The Lidar survey as applied to two bridges over the Interstate I-70 provided models within 48 hours. This period includes lidar data collection and analysis.

Implementation

Lidar surveys can immediately implemented as part of standard survey operations for as-built and design applications. The technique is accurate with proper control and very timely. The technique has the potential to contribute substantially to so-called virtual survey office models whereby costly trips back to the field are avoided. Changed insights in survey

parameter extraction do not require return to the field either. Since Lidar is basically a line-of-sight technique possible obstruction may occur. Hence planning of Lidar surveys does not only include the necessary control for correct geopositioning of point clouds but also careful planning of Lidar system set-ups to avoid line-of-sight obstruction.

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1. The centerline of the bridge/road as obtained from MXRoads Dataset
2. The divider on the bride/road as obtained by Lidar system
3. The inner edges of the bridge/road centerline as obtained by the lidar system
4. This line segment is perpendicular to the red line described in statement 3 and
5. This is a cursor at the center of the line segment described in statement 4.

Figures 2a, b. Comparison in the Horizontal plane

The left image is taken from the Northern (North West) end of the bridge and the right image from the southern (South East) end. The cursor position represents the ideal location of the centerline with respect to the Lidar dataset. The discrepancy between the Lidar dataset and MXRoads data, as shown in the above two figures is 0.125 ft in the Northern end and .075 ft at the Southern end of the bridge respectively.

Position of Sampled data	Horizontal Difference between MXRoads and Lidar data
Northern End	0.125 ft/3.81 cm
Southern End	0.075 ft/2.29 cm

Figure 3. Comparison in the Vertical Direction

1. Selected points on the surface of Bridgeport from the Lidar data, at the northern end	2. Selected points on the surface of Bridgeport from the <i>MXRoad</i> data, at the northern end
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1. Represents a point from the Lidar Point Cloud (figures left column)
2. Represents a point at the same horizontal location as the point described under 1 (figures right column).

Sample Points	Vertical Difference between MXRoads and Lidar data
1	0.025 ft/0.76 cm
2	0.017 ft/0.51 cm
3	0.05 ft/1.52 cm

Figure 4. Engineering Applications Using Laser Scanning

Mid-part of Bridgeport bridge, as point clouds represent it

Mid-part of Bridgeport bridge, after being modeled

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16. Abstract <p>Design data collection involving the use of Lidar instrument, in conjunction with GPS proves to be very effective. Data required to model two bridges over the I-70 was collected on a single day, involving five and six sessions with Lidar equipment. Even though the data was collected on two bridges, it did not cause any disruption of the traffic, either on the Interstate or on the bridges. A major cause of concern during survey activities, particularly along interstates is safety, both for the motorists as well as the people involved in data collection. Lidar data collection was found to be extremely safe in both aspects.</p> <p>The whole process of collecting Lidar data and GPS coordinates for control was completed in 2 days for both bridges. Office work involved combining the GPS data with conventional survey data to bring control on six pre-selected points within the Lidar point cloud. This control information was later used to bring the point cloud into a geographic coordinate system.</p> <p>This survey provided the means to compare the 3D point cloud with bridge designs that were created using other methods of data collection. It was found that the 3D point cloud exhibits a very high degree of accuracy, both internally and also when geo-referenced independently using GPS and conventional control survey. The Lidar model was compared to the MXRoad data model provided by INDOT. The discrepancies between the two models were not larger than 0.125 ft/3.81 cm horizontally and 0.05 ft/1.52 cm vertically.</p> <p>The data collected completely modeled the bridge and the accuracy of the data ensures that any model of the bridge, either as a whole or in part, will correctly reflect the current state of the bridge. The data collected can also be used for various applications including cut-and-fill estimates, modeling the state of the bridge, making measurements on various parts of the bridge.</p> <p>A cause of concern is the amount of data involved. As millions of 3D points are collected, popular CAD/GIS packages are unable to deal with it. For this reason proprietary software, designed particularly to handle such huge volumes of data involved, was used for analyzing this data. However, it is possible to export data from this software to other commonly used CAD packages.</p> <p>Using satellite imagery instead of aerial photos may provide faster results to investigate the project area. Conversion of the MXROAD data into the ArcGIS system is not easy, but it is hoped that this problem can be solved very easily. The Lidar point cloud should be processed and a CAD model of the data should be obtained to obtain more useful information. With the help of the GIS a variety of data sources and types can be integrated, visualized and used to make about resource management, and perform modeling and analysis. GIS helps organize bridge management information contained in various forms, such as inspection reports, rehab plans, and CAD files. Maintenance management and asset valuation may be enhanced with GIS and linear referencing systems.</p>			
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CHAPTER 1 Introduction

During the summer of 1999 a number of focus groups were formed to make recommendations to the Indiana Department of Transportation regarding topics and priorities for a long range research plan. One of the groups looked at the combined areas of Construction and Surveying. This group had discussions, sought external input, sought faculty input and ultimately submitted its recommendations in December, 1999. This report, along with other focus group reports, were reviewed and refined by the Board of the Joint Transportation Research Program, and published in a Draft Final Report in February, 2000.

The focus group had recommended eleven projects, and, of those, number one and number three in the priority list were: "Modern Technologies for Design Data Collection", and "As Built Data Collection Using Modern Technologies" respectively. The Board recommended that these be combined into a single project, and this proposal is in response to that recommendation.

The need for this research was motivated by the realizations that (1) field data collection is a very time consuming, labor intensive and error prone activity, and that (2) this is a field of frenetic research and development efforts by commercial equipment manufacturers and by academic researchers. A prudent organization would reassess their data collection methods every few years to permit them to take advantage of advances and innovations in the technology.

The authors of this proposal have identified a number of new data collection technologies that appear to have merit for use by INDOT, and in some cases, these technologies are developing established track records of success in use by comparable organizations. After some discussions with INDOT personnel, however, it was decided to defer any pilot projects, system evaluations, data analysis, etc. until a thorough understanding had been achieved of the current methods in use, and how they fit into the planning, design, construction, and as-built evaluation activities. This will insure that whatever methods are

eventually selected for testing and analysis will be relevant to the data flow and operational constraints within INDOT. As such, the proposed schedule will have an initial period of interviews and familiarizations with typical project parameters before beginning the actual work of evaluating data collection technologies. Particular attention will be paid to issues of database formats, CAD data formats, and other software standards so that any data sets produced would be compatible with existing analysis tools. Nevertheless, to look ahead, we will suggest some likely candidates for consideration when the decisions are eventually made about which areas of measurement and which data collection technology appear to be the most promising.

CHAPTER 2. Technologies vs. Design Software

2.1 Construction Data Collection

The modern technologies such as high resolution satellite data, Global Positioning System (GPS) field data collection, tripod mounted laser scanning, and airborne laser scanning are applicable for design data collection. Remarkably GPS among notified modern technologies has been utilized actively in construction activities until now.

Construction industry took GPS technologies slowly considering the strengthens and efficiency of GPS, since people in construction industry worry about military involvement until the US Congress passed legislation for civil use of GPS. Another reason of slow take up is the technology was not recognized as being as accurate or as mature as it was. However, there was long period of slow take up as the technology matured in construction industry but as it matured, the speed of application has accelerated.

We will be exploring the applicability of the modern technology for construction projects.

2.2 Cost Analysis

A variety of technologies have been used to construction activities. In last decade, the Global Positioning System (GPS) among the modern technologies has been applied to various fields of construction activities such as surveying, real-time positioning, construction equipment (i.e. pavers, compactors, etc.). According to the research until now, the application of GPS has provided a good effect on construction project: increased productivity, less rework, and safety issue as well.

2.3 Highway Design Software

The following will briefly outline some of the civil design systems available today: GEOPAK, Intergraph InRoads, Eagle Point, Softdesk, GDS and MOSS. The list of

software tools covered here is by no means comprehensive, but was intended to be representative of what is available in the marketplace. There are many fine products available that were not included in the discussion.

(http://ntl.bts.gov/DOCS/96134/ch03/body_ch03_03.html)

Following is the table of comparison of Highway Design Software Used in US State DOTs.

Table 2.1. The Comparison with Highway Design Software Used in US State DOTs

Specification	MX roads	GEOPAK	InRoads	Eagle Point	Softdesk	GDS CADD
Features	<ul style="list-style-type: none"> - Internationally recognized - Stand-alone package - Unique methodology of representing design surfaces 		<ul style="list-style-type: none"> - A leader in the civil design software industry - In the market for 10 years 	An integrated software for the architectural, landscaping, civil engineering, and GIS	<ul style="list-style-type: none"> - The largest vendor of AutoCAD application - An integrated software for the architectural, landscaping, civil engineering, and GIS 	<ul style="list-style-type: none"> - Internationally recognized - An infrastructure / facilities management system
Software Modules		<ul style="list-style-type: none"> - Road - Site - Survey - Earthworks 		<ul style="list-style-type: none"> - Surface Modeling - Site Design - RoadCalc - Profiles 	<ul style="list-style-type: none"> - Digital Terrain Modeling - Earthworks - Design - Advanced Design 	
Cooperation with		Bentley systems' Microstation CADD platform	Own Intergraph product	Bentley systems' Microstation CADD platform		

Specification	MX roads	GEOPAK	InRoads	Eagle Point	Softdesk	GDS CADD
Operating System / Platform	<ul style="list-style-type: none"> - DOS - Windows - Windows NT (Future) - Unix - VMS 1. Windows version - Uses its own graphics in Windows environment 2. AutoCAD version - Runs in the AutoCAD environment using AutoCAD graphics and modified AutoCAD menus 3. Microstation version - Runs in the Microstation environment using Microstation graphics and modified Microstation menus 	<ul style="list-style-type: none"> - DOS - Windows - Windows NT - Unix - Intergraph Clipper Workstation - Bentley systems' Microstation CADD platform 	<ul style="list-style-type: none"> - DOS - Windows - Windows NT - Unix - Intergraph Clipper Workstation - VMS 	<ul style="list-style-type: none"> - DOS - Windows - Windows NT - Unix - Intergraph Clipper Workstation - Bentley systems' Microstation CADD platform - Autodesk's AutoCAD platform 	<ul style="list-style-type: none"> - DOS - Windows - Windows NT - Unix <p>Autodesk's AutoCAD platform</p>	<ul style="list-style-type: none"> - Unix - VMS
Base Language		<ul style="list-style-type: none"> - "C" programming - Microstation's MDL language 	<ul style="list-style-type: none"> - Microstation's M DL language 			

Specification	MX roads	GEOPAK	InRoads	Eagle Point	Softdesk	GDS CADD
Generated File Type	DXF file compatible with AutoCAD Microstation DGN format	Microstation DGN format	Microstation DGN format	- Microstation DGN format - AutoCAD DWG		
Offering Library Application		Yes	Software Developers Kit for an additional fee	- ADS for AutoCAD r12 - AutoLISP for AutoCAD r13 including ARX	- ADS for AutoCAD r12 - AutoLISP for AutoCAD r13	
Integration with CADD package	Own graphical interface	Microstation CADD				
Software Operation	Stand-alone package providing DXF level compatibility with AutoCAD providing DGN level compatibility with MicroStation	- Graphical display engine for external data - Identical across each platform - Binary compatible across all platform	- Binary compatible across all platform - Supporting AutoCAD environment - The external project is saved in its own proprietary binary format	The external data file format is a proprietary binary format compatible with Microstation and AutoCAD for input	The external data file format is a proprietary binary format	Object oriented data structure and tight links to back end data bases

Specification	MX roads	GEOPAK	InRoads	Eagle Point	Softdesk	GDS CADD
Strengthens	<ul style="list-style-type: none"> - Internationally recognized - Using 3D data “strings” to model surface features 	<ul style="list-style-type: none"> - Comprehensiveness - Fully exploit the Microstation’s interactive - Flexibility - Easiness for use of graphic interface - Utilizing MDL - Change the geometry of the graphics and update or produce the external data 	<ul style="list-style-type: none"> - Fully exploit the Microstation’s interactive - Flexibility - Easiness for use of graphic interface - Change the geometry of the graphics and update or produce the external data 	Change the geometry of the graphics and update or produce the external data	Change the geometry of the graphics and update or produce the external data	
Weakness					Slow acceptance of PC based CADD and AutoCAD in general in the public sector	

Specification	MX roads	GEOPAK	InRoads	Eagle Point	Softdesk	GDS CADD
Cost	<p>\$5,500 with a \$975 annual maintenance for Mxroad MAX including MX ROAD/MX RENEW/ MX DRAW</p> <p>\$ 1500 for 1 student for full day</p> <p><i>\$5000 for 6 to 8 engineers</i></p> <p><i>The commercial version includes the Windows environment and a choice of CAD environments. For an additional \$750, both CAD environments are supplied with the commercial version.</i></p>	\$6,525	<p>\$6,000</p> <p>\$6,000 Maintenance per month is \$100</p> <p>Free upgrades</p> <p>On-site training at \$165 per hour.</p>	<p>\$5,000 for one seat of software.</p> <p>Training cost is \$1195.00 per person</p> <p>Maintenance:</p> <p>Bronze Level: \$2250.00 per year per seat, no limit to the number of modules you have.</p> <p>Silver Level: \$1960.00 per year, per seat. Must have 50 modules or more for this level.</p> <p>Gold Level: \$2450.00 per year, per seat. Must have 50 modules or more for this level.</p>		
3D data to model surface features	<i>“Strings”</i>					

Table 2.2. Legend for Table 2.1

Acronym	Definition
ADS	AutoCAD Development System
ARX	ARX
AutoLISP	AutoLISP is the scripting language for AutoCAD by Autodesk, a very crippled dynamic Lisp-1, based on very early xlist sources (v1.0), posted by David Betz on usenet (alt.sources), and without proper copyright laws that time used by Autodesk as their free scripting language.
CADD	Computer Aided Drafting and Design
DGN	Design
DWG	AutoCAD File (File extension)
DXF	AutoCAD File (file extension)
GDS	Graphic Design Software
MDL	MicroStation Development Language (C-like programming language for MicroStation)
VMS	The official name of VMS is currently OpenVMS. VMS is a product of Compaq (after Compaq bought Digital). VMS currently supports two hardware platforms: VAX and Alpha, and the variants are known as VMS VAX and VMS Alpha (or OpenVMS VAX and OpenVMS Alpha).

CHAPTER 3 Laser Scanning

3.1 Introduction

Laser scanning is a new technology that enables users to collect accurate geometrical as-built data to be used later on for all kinds of applications, from military and space to movie and entertainment. When activated, a laser scanner would send hundreds of laser beams per second towards a user-specified object and retrieve these beams back, thus measure the 3D position of each single point hit by each beam in the laser scanner's arbitrary local coordinate system with millimeter accuracy. All these positions are saved in fully digital environment. This technology has several advantages, such as the ability to capture detailed as-built description of objects out of reach and in short times.

In this pilot project, two companies were subcontracted to laser scan Bridgeport bridge and Six Point bridge. Namely, Toronto-based Optech Incorporated¹ and Indiana-based Falk PLI². On May 27, 2002 Optech carried out the laser scans of both bridges using ILRIS-3D laser scanner. On the other hand, Falk PLI carried out the laser scan of Bridgeport bridge on September 26, 2002 using Cyrax 2500³ laser scanner, while rain prevented the scan of Six Point bridge.

Although all point clouds can be exported into various CAD software packages like AutoCAD, the huge amount of points (i.e. millions) could not be handled in these packages. For the sake of processing the point clouds collected both by ILRIS-3D and Cyrax 2500 laser scanners, the choice was made to use a software package called Cyclone. Basically, it's the same software used along with various types of Cyrax laser scanners in the field.

¹ <http://www.optech.on.ca>

² <http://www.falk-pli.com>

³ <http://www.cyra.com>

3.2 Optech Survey

Bridgeport bridge was scanned before noon on May 27, 2002. It took twelve scans to cover the whole bridge; five from east, five from west and two from the top of the bridge. Six Point bridge was scanned in the afternoon, where it took ten scans to cover the whole bridge; five from east, three from west and two from the top of the bridge, as seen in Figure (3.1) below.

Figure 3.1: The scope of Optech's twelve scans of Bridgeport bridge

The laser scanner, shown in Figure 3.2, is guided and controlled by a hand-held computer that connects to it thru infrared link, cordlessly. Optech Incorporated uses a partner software package called PolyWorks produced by Québec-based InnovMETRIC Software⁴ to process its point clouds. Because of the unavailability of this package with its full functionalities, the point clouds were imported as X-Y-Z coordinates into Cyclone.

⁴ <http://www.innovmetric.com>

Figure 3.3 below shows the very first scan of Figure 3.1 as seen in PolyWorks' viewer only version.

Figure 3.2: The ILRIS-3D laser scanner

Figure 3.3: The first scan in Figure 3.1 as appears in PolyWorks' viewer only version

The multiple scans were registered together (i.e. overlapped on each other to produce the final shape of the target object) as pairs without using control in the field. PolyWorks

enables the user to manually define common points in two point clouds and then register one of them to the other. Then the user proceeds to register this result point cloud to a third point cloud (or vice versa) using common points between them. For the case of Bridgeport bridge, this continued until all twelve scans were registered to each other and the combined scan looked like Figure 3.4 below, artificially colored by the user, with total of 1,219,466 points.

Figure 3.4: Image of Bridgeport bridge and 3 zoomed in images, as scanned by ILRIS-3D

The absence of control is advantageous when scanning objects out of reach and when providing sufficient control is impossible. But again, sharp recognizable points are needed to carry out the manual registration process. On the other hand, control points make the registration process easier and faster. From a qualitative point of view, doing registration with sharp control points would be more accurate, since no manual interference is done. If the operator who is doing manual registration is excellent, he can achieve the kind of accuracy achieved with control points, but cannot exceed it. This is because the operator would do his best to assure usage of sharp recognizable point in both point clouds, which is already achieved with control registration. However, if the user has excellent skills in this aspect and can make usage of more points (e.g. twenty) to register the point clouds while there exist less control points (e.g. five), this may make manual registration advantageous.

3.3 Falk PLI Survey

Bridgeport bridge was scanned before noon on September 26, 2002. It took seven scans to cover the whole bridge; two from east, three from west and two from the top of the bridge. A special high tripod was used to scan the top of the bridge, to get a wider perspective of the bridge and to capture one of the control points to the west of the bridge, located on the southern shoulder of I-70. This tripod is seen in Figure 3.5 below.

Figure 3.5: Special tripod for Cyrax 2500

The laser scanner is guided and controlled by a laptop that connects to it thru cables. It also needs its own power generator, as seen in Figure 3.6 below.

Figure 3.6: Snapshot of a scan taken from the east of Bridgeport bridge

The laser scanner shown in Figures 3.5 and 3.6 uses special arrangement of spheres for control, so that multiple point clouds can be registered onto each other using any single scan of them as reference, or they can be registered to global coordinates if known. These spheres are in reality semi-spheres that look like those seen in Figure 3.7, but when they are modeled, they look like Figure 3.8. As explained in other chapters, the positions of three of the spheres were measured directly by GPS and the positions of the other three spheres were extrapolated using topographic surveying technique with software called Move3⁵.

Figure 3.7: Semi-spheres scanned by Cyrax 2500 and to be modeled by Cyclone, on Bridgeport bridge

Figure 3.8: Sphere mounted on tripod, modeled to serve as control point

A problem was faced during registering the bridge to the GPS coordinates. Some control points were off by more than 2 meters. The source of the problem came out to be mislabeling of spheres due to extreme symmetry, as seen in Figure 3.9. Thus, it is thought

⁵ <http://www.move3.com>

to be very important to position the control points in a non-symmetrical configuration to avoid such mislabeling.

Figure 3.9: Symmetry of control points

After fixing this problem and all control points have been labeled correctly, the maximum error came out to be 1.4 cm/0.046 ft only, as seen in Appendix E. Figure 3.10 shows a snapshot taken from inside a sphere, where the blue vertex is the GPS control point while the grey vertex is the center of the modeled sphere. Table 3.1 shows part of the diagnostics report of the registration.

Figure 3.10: Sample error when registering all point clouds to GPS coordinates

Table 3.1: Part of registration diagnostics report

Point's ID	Point Cloud to be Registered	Control Point Cloud	Type of Objects Registered	Error (m)	Error Vector (m)
S5	ScanWorld 6	FINAL c6pts	Sphere-Vertex	0.006	(0.004, 0.003, 0.001)
S6	ScanWorld 6	FINAL c6pts	Sphere-Vertex	0.009	(0.008, 0.002, -0.003)
S4	ScanWorld 6	FINAL c6pts	Sphere-Vertex	0.007	(0.000, -0.001, 0.007)
S2	ScanWorld 6	FINAL c6pts	Sphere-Vertex	0.007	(-0.002, -0.005, 0.004)
S3	ScanWorld 6	FINAL c6pts	Sphere-Vertex	0.014	(-0.005, 0.004, -0.013)
S1	ScanWorld 6	FINAL c6pts	Sphere-Vertex	0.006	(-0.005, -0.002, 0.000)
S2	ScanWorld 7	FINAL c6pts	Sphere-Vertex	0.006	(-0.002, -0.005, 0.002)
S1	ScanWorld 7	FINAL c6pts	Sphere-Vertex	0.004	(-0.004, -0.001, 0.002)

The whole bridge registered to real world GPS coordinates looks like Figure 3.11, artificially colored by Cyclone itself, with total of 2,756,495 points.

Figure 3.11: Bridgeport bridge registered to GPS coordinates, with 4 zoomed in images

3.4 Time taken for Data Collection

The time required to collect data using both Optech and Cyrax instrument was around the same. For a single bridge, six hours was needed to scan the bridge completely from different positions.

3.5 Alignment with MXRoad data

Many engineering applications can be done using this, such as modeling, volume measurement, distance measurement, meshing...etc. All these applications will be discussed in the coming pages. On the other hand, the first thing to be explored here is the feasibility to register the bridge to the point cloud exported from *MXRoad*⁶ (the software package of choice at INDOT) as X-Y-Z format in UTM (NAVD83). First, the point cloud from MXRoad is imported into Cyclone and it appears as seen in Figure 3.12. The fact that it has only 107,532 points makes it easily handled by Cyclone

⁶ <http://www.cadapult-software.com>

Figure 3.12: Data imported from *MXRoad*

When zooming in Bridgeport bridge, it looks like Figure 3.13.

Figure 3.13: Bridgeport bridge as in the data imported from *MXRoad*

As explained before when all the point clouds captured by Cyrax 2500 laser scanner were registered to GPS coordinates, the same six control points on Bridgeport bridge can be used to register all these point clouds to UTM. Using Move3 and constraining the elevation to the elevation control point of G163 available on Bridgeport port of 770.83 ft, seen in Figure 3.14, all the control points where acquired in UTM.

Figure 3.14: Vertical control point of G163 on Bridgeport bridge

Using Cyclone to register all the point clouds to UTM and overlapping them onto the point cloud imported from *MXRoad* resulted in good overlap results, as generally seen in Figure 3.15.

Figure 3.15: Point clouds of laser scanning correctly geo-positioned onto *MXRoad* data

Zooming in further more and checking the centerline of I-70 represented in the *MXRoad* data with the lidar data shows good overlap, shown in Figure 3.16. To confirm this

overlap, the centerline of I-70 seen in Figure 3.16 was modeled as a blue line and the middle pillar of Bridgeport bridge was cut horizontally to visually evaluate the quality of the overlap. This confirmed the good overlap across the I-70, as seen in Figure 3.16.

Figure 3.16: Good overlap of lidar data on *MXRoad* data across the I-70

Figure 3.17: Confirmation of the good overlap of lidar data on *MXRoad* data across the I-70

As the overlap across the I-70 (along Bridgeport bridge) has been confirmed, the overlap across Bridgeport bridge (along the I-70) needs to be inspected too. This was done by looking at the centerline of Bridgeport bridge itself. Again, as Figure 3.18 shows, good overlap exists. To confirm this overlap, the centerline of Bridgeport bridge was modeled as blue line. As seen in Figure 3.19, the overlap is good.

Figure 3.18: Good overlap of lidar data on *MXRoad* data across Bridgeport bridge

Figure 3.19: Confirmation of the good overlap of lidar data on *MXRoad* data across Bridgeport bridge

By looking from the side at the bridge as shown in Figure 3.19, after keeping only the points representing the bridge's road surface, it is interesting to see how the lidar point

clouds represent the curvature of that surface when compared to the blue straight line generated to model the centerline from *MXRoad* data, as seen in Figure 3.20.

Figure 3.20: Curvature of the Bridgeport road surface, represented by lidar data

In order to quantify the precision of the alignment shown in Figure 3.19, the centerline data from *MXRoad* is modeled as green lines at each end. This is done because the long blue line seen in Figures 3.19 and 3.20 extends along the whole bridge, which may cause it to deviate since the bridge isn't perfectly straight. Then, two red straight lines are drawn along the inner edges of the solid 2 yellow lines (appear as two thick lines in Figure 3.21) that run thru the middle of the bridge's road surface. The distance between these two lines is represented by the magenta line in Figures 3.21 and 3.22. The blue cursor seen in Figure 3.22 is placed at the exact center of the magenta line. Ideally, the green line should have been coincident with the blue cursor. However, it's 0.125 ft off at the northern end, as seen in Figure 3.23. The same procedure was repeated at the southern end and the center of it was measured 0.075 ft off. On the other hand, it's not known if the *MXRoad*'s centerline actually represents the exact mid-distance between the two solid yellow lines in the field. Thus, these deviations simply represent the difference between the two datasets, and not errors in any. Nevertheless, the fact that centerline of *MXRoad* is perfectly located within the two scanned lines indicate the high precision of the point

clouds and registration processes carried out until now. The analogous deviation in Figure 3.17 is no more than 0.125 ft too.

Figure 3.21: Magnified image of northern end

Figure 3.22: Figure 3.21 magnified further more

Figure 3.23: Discrepancy between *MXRoad*'s centerline and lidar's centerline at northern end

Figure 3.24: Discrepancy between *MXRoad*'s centerline and lidar's centerline at southern end

All these tests confirm the high quality of horizontal coordinates of the lidar point clouds. To check the vertical quality of the coordinates, few points were checked. Figures 3.25 and 3.26 show a comparison done on the surface of I-70 with a difference of 0.025 ft in the heights, Figure 3.27 and 3.28 show a comparison done on the bridge's road surface at the northern end with a difference of 0.017ft, and finally Figures 3.29 and 3.30 show a comparison done on the bridge's road surface at the southern end with a difference of 0.05 ft. Vertical consistency is confirmed and seems excellent too.

Figure 3.25: Picked point on the surface of I-70 from the lidar data

Figure 3.26: Picked point on the surface of I-70 from the *MXRoad* data

Figure 3.27: Picked point on the surface of Bridgeport from the lidar data, at the northern end

Figure 3.28: Picked point on the surface of Bridgeport from the *MXRoad* data, at the northern end

Figure 3.29: Picked point on the surface of Bridgeport from the lidar data, at the southern end

Figure 3.30: Picked point on the surface of Bridgeport from the *MXRoad* data, at the southern end

3.6 Test Laser Scan at US 52 – Northwestern Avenue

Before carrying out the laser scans at Bridgeport bridge illustrated above, the technology of laser scanning was tested at the bridge of Northwestern Avenue over US 52 at West Lafayette, IN. This scan was carried out on May 2002 by Falk PLI using Cyrax 2500 laser scanner.

Figure 3.31: Northwestern Avenue's bridge on US 52 in West Lafayette, IN

The impressive results obtained here were the major motivation to inspect this technology further more in the pilot project conducted on Bridgeport bridge and Six Point bridge on I-70.

3.7 Engineering Applications

As mentioned before, various engineering applications can be done with such dense Lidar point clouds like modeling, volume measurement, distance measurement, and meshing as long as the software package is efficient in handling such huge volume of points.

Modeling has always proved itself as an application of necessity and preference by engineers. In order to demonstrate the modeling capability, the middle part of Bridgeport Bridge seen in Figure 3.32 has been chosen. The planar surfaces, like the surface of road, have been modeled by fitting a patch to each point cloud in it, then all the fitted patches have been merged together producing the best fit for all the point clouds representing that surface. Only the bottom half of the steel sections in between the pillar and bridge deck were scanned. Had it been the intention to scan them, they could have been scanned in full. Since only half of each steel section is present, each half has been modeled by fitting a T-section to it, then an exact copy of this section was rotated 180 degrees around its long axis, producing an I-section. The barrels on the sides of the pillar were modeled by fitting cylindrical bodies to them, then fitting semi-elliptical end cap at the top and flat end cap at the bottom of each. The barriers were modeled by fitting approximate T-sections to the irregular vertical objects and line segments to the horizontal ones. There are many ways to model the pillar, but only one way would enable the later measurement of its volume. In order to be able to do that, one side of the pillar was modeled as a patch, then it was extruded giving a 3D object. The steel boxes carrying the steel sections on the pillar were modeled as traditional boxes. The model is as seen in Figure 3.33.

Figure 3.32: Mid-part of Bridgeport bridge, as point clouds represent it

Figure 3.33: Mid-part of Bridgeport bridge, after being modeled

As mentioned above, the pillar was modeled in a way to enable its volume measurement, which is another application many engineers would be interested in. The way of modeling may differ from a software package to another, but the ability to rapidly scan a big object

in the field with challenging accessibility circumstances, and then measure its volume in the comfort of office is certainly something engineers would like to have. Measuring the volume of that pillar reveals 16.584 m^3 , which is equivalent to 585.668 ft^3 as seen in Figure 3.34.

Figure 3.34: The volume of modeled 3D bridge pillar

It should be noticed that the measured volume is as good as the model itself.

Also, engineers at the design stage would be very interested in knowing the amount of soil to be removed to achieve a certain target within a certain area, or the amount of soil above a certain reference plane that the design requires in that area. This task can be easily achieved with laser scanning. The area under inspection should be scanned and the point clouds belonging to any unnecessary objects can be removed. Then, the surface of soil can be modeled using the meshing function, which doesn't require regular or smooth surfaces. After the soil is meshed, engineers can start assigning new reference planes to achieve the volume of soil cut they are after. To apply these concepts on the case study in hand, everything but the ground surface was removed. The ground surface in this case

would be the I-70 road surfaces and whatever is in between the two bounds and the under-bridge concrete embankments. An arbitrary coordinate system was assigned with its X-Y plane within the I-70 plane. This forced the local Up Direction to be along the local Z axis. Then, all the point clouds in hand were meshed and elevation contours at 1-meter interval were plotted, as seen in Figure 3.35.

Figure 3.35: Meshed surfaces and elevation contours

By assigning an arbitrary reference plane, the volume of material between the mesh and the reference plane can be measured easily. As seen in Figure 3.36, a volume of about 1945 m^3 (equivalent to 68705 ft^3) needs to be removed to achieve that reference plane in particular. If the design engineer wishes to have deeper or shallower cut, all he/she needs to do is to lower or raise the reference plane and re-measure the new cut volume. Vice versa, if the design necessitates certain amount of cut volume, then the necessary depth can be measured easily. Also, the ability to have local elevation contours at any desired interval enables the design engineer to sub-divide the area into various regions and carry out various similar sub-analyses. All these tasks can be done in any user-defined coordinate system or mapping project, as long as control points are available to carry out efficient registration (transformation) process.

Figure 3.36: Volume between mesh and reference plane

Few results of the volume between the mesh and reference plane (seen as green grid in Figure 3.36) with different depth values of the reference plane are given in Table 3.2.

Table 3.2: Volume of soil under I-70 and embankments at sample depth values

Depth	Volume between mesh and reference plane (feet ³)	Volume between mesh and reference plane (meter ³)
0.0	54486	1542
-1.0' ($\approx$ -0.305m)	65228	1847
-2.0' ($\approx$ -0.610m)	76171	2157
-3.0' ($\approx$ -0.915m)	87115	2467
-4.0' ($\approx$ -1.220m)	98058	2777

Doubtlessly, distance measurement is another major application. For example, clearances need to be determined on regular basis. Figure 3.37 shows an example provided to us by INDOT, where the clearances of northbound I-69 over US24 are measured at certain intervals.

Figure 3.37: Example sketch of bridge clearances

When dealing with laser scanning point clouds, measuring distances can be done in many forms. A smart way to do it is by efficient usage of coordinate systems. For example, measuring the vertical spacing seen in Figure 3.37 can be done by assigning an arbitrary local coordinate system with its Z-axis along the middle pillar upwards, then measuring the differences between the Z coordinates of points would give the clearances. The horizontal distances seen in Figure 3.37 can be measured by assigning the X-axis of that coordinate system along the bridge, and simply taking the differences between the X coordinates of the points. Ideally, the road's surface should be scanned well beneath the bridge to carry out such analysis. However, this application wasn't thought of when the laser scan was carried out in this pilot project. Nevertheless, the scanned amount of the I-70's surface is sufficient to show an example of the feasibility of this application, though the results here are not thought to be as precise as this technique traditionally could provide. In this case, the Z-axis was assigned up along the pillar shown in Figure 3.34, and the X-axis was assigned along the bridge. The result clearance values are shown in Figure 3.38 and in Table 3.3

3.8 System requirements

The data collected by the lidar system for most projects will be huge. Therefore a computer of sufficient Hard Drive memory as well as Random Access Memory is

required. For this project, the computer system that was used was an Inter Pentium IV with a 2.4 GHz processor and 1.00 GB of RAM. A software Cyclone from Cyrax was

Figure 3.38: Bridgeport bridge clearance over I-70

Table 3.3: Clearance values of Bridgeport bridge over I-70 at sample intervals

Distance from northern pillar	Clearance of Bridgeport bridge over I-70
9.16'	16.34'
20.72'	16.22'
32.69'	16.19'
45.07'	16.33'
82.68'	16.37'
94.38'	16.24'
106.04'	16.28'
117.43'	16.39'

leased and installed on this computer. The software is standalone software and was used for all the analysis, including point cloud registration, measurements, feature extraction etc. One of us had worked with this software for 2 months prior to this project. However, learning the software should not take more than a week, as it is very intuitive.

Although the amount of lidar data collected is huge, the engineer will only be interested in information, such as the as built model, etc. that can be extracted from the data. This information will be much more manageable and easy to work with than the raw data itself, and can be imported into existing formats of CAD or MxRoads etc.

CHAPTER 4 Satellite Imagery (QuickBird Image Rectification)

This chapter documents the generation of the rectified QuickBird satellite image of the project area.

4.1 Summary

The rectified image of the area surrounding the interstate between the Six Points and Bridgeport Overpasses was created from a QuickBird 2 satellite image using a 0.60m resolution grid. The rectified image has the UTM (zone 16) coordinates shown in Figure 4.1. The area was chosen to best enclose the coordinates (Easting: 552323 to 559376 m and Northing: 4389800 to 4394761 m) covering the project area. The rectification was completed using a resected satellite “push broom” model. The resection was based on a least-squares fit using nine photo-identifiable control points that were surveyed using a handheld GPS receiver. Furthermore, the rectification was performed using a constant elevation of 190 m HAE. Both the lack of accurate ground control and terrain elevation data will contribute to inaccuracies in the rectified image. The fact that the image was collected from a near-nadir position reduces the contribution of elevation errors; nevertheless, it is assumed that the horizontal positional accuracy of the image is no better than 5-8 meters.

Figure 4.1 Rectified Satellite Imagery

The following paragraphs provide additional details concerning the individual elements of image rectification.

4.2 Original Image

The original image was collected using Digital Globe's QuickBird 2 satellite. The image was collected at approximately 11:30 AM local time on January 15, 2003. The image contains 30,004 by 27,552 eleven-bit grayscale pixels. The average ground sample distance is approximately 0.61 m per pixel. The original image is shown in Figure 4.2. The approximate area used in the rectification is also indicated in the image. The locations of the control points used for the resection are also indicated. Before the image could be rectified, a portion of the image around the area of interest was extracted (using ArcGIS) and converted to 8-bit depth (using MatLab).

Figure 4.2 Original Satellite Imagery

4.3 Ground Control Points

The geodetic coordinates (including height above ellipsoid—HAE) of the nine control points indicated in the previous image are listed in Table 4.1. These coordinates were obtained during the month of March 2003 by Professor Bethel using a handheld GPS receiver and are assumed to be accurate to within 8 m horizontal (1σ) and 15 m vertical (1σ). The UTM coordinates were obtained using NIMA's GeoTrans software. The table also lists the corresponding pixel measurements for each of the control point features in the satellite image.

Table 4.1 Geodetic Coordinates of The Nine Control Points

Pnt	Geodetic Coordinates			UTM (m)		Image Coordinates	
No.	North Lat	West Lon	HAE (m)	North (Y)	East (X)	Line (y)	Sample (x)
1	39: 46: 40.4	86: 22: 47.7	227.4	4,403,289	553,101	2,274.1	1,287.1
2	39: 46: 54.7	86: 17: 50.2	204.5	4,403,783	560,175	1,601.7	12,754.9
3	39: 47: 01.6	86: 11: 47.4	180.7	4,404,068	568,803	1,286.4	26,806.6
4	39: 42: 43.1	86: 22: 56.4	201.4	4,395,972	552,945	14,219.6	920.6
5	39: 43: 56.3	86: 18: 36.7	196.9	4,398,274	559,111	10,562.9	10,958.0
6	39: 42: 47.1	86: 13: 42.5	178.6	4,396,198	566,133	14,051.1	22,363.0
7	39: 40: 22.7	86: 22: 07.7	194.5	4,391,652	554,135	21,296.4	2,793.4
8	39: 37: 53.7	86: 18: 38.6	207.5	4,387,095	559,152	28,875.6	10,882.1
9	39: 37: 38.5	86: 12: 13.5	171.9	4,386,702	568,336	29,563.4	25,871.0

4.4 Linear Transformation Model

As an intermediate step, the QuickBird image was modeled with a simple linear transformation. Using the nine control points above, a fit was made to such a model. This model uses the six-parameter transform described by the following equation:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} s_X & 0 \\ 0 & s_Y \end{bmatrix} \begin{bmatrix} 1 & k \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} X' \\ Y' \end{bmatrix} + \begin{bmatrix} t_X \\ t_Y \end{bmatrix} = \begin{bmatrix} a_1 & a_2 \\ b_1 & b_2 \end{bmatrix} \begin{bmatrix} X' \\ Y' \end{bmatrix} + \begin{bmatrix} a_0 \\ b_0 \end{bmatrix}$$

where (x', y') are the pre-shifted and scaled image coordinates and (X', Y') are the pre-shifted and scaled UTM ground coordinates¹. The model allows for an additional translation (t_X and t_Y) and scaling (s_X and s_Y) of the X' - and Y' -axes, a rotation (θ) about the vertical, and a skewing (k) of the axes to allow for non-orthogonality in the image. These six parameters were combined into the six elements a_i and b_i as shown above. Only three control points would be needed to completely define these six parameters. The redundancy provided by the nine control points allowed for a least-squares fit. The computed values for these six composite elements are indicated in the following table below with the pre-transformation shifts and scalings for the coordinate systems. The resulting residual for each control point measurement is presented in Table 4.2.

Table 4.2 Resulting Residuals for Each Control Point

Param	Value
a_0	-0.00445502007161
a_1	0.99654438160144
a_2	0.00805791104357
b_0	-0.00797384895740
b_1	0.00866032020995
b_2	-1.00249013896821
X_{shift}	13863.6
Y_{shift}	15424.9
X_{scale}	12943.0
Y_{scale}	14138.5
X_{shift}	560874.0
Y_{shift}	4395385.0
X_{scale}	7929.0
Y_{scale}	8683.0

Cntrl Pnt	Residuals in Pixels		
	x	y	radial
1	30.7	-15.9	34.6
2	-14.8	8.8	17.3
3	-1.9	25.5	25.6
4	5.9	-11.9	13.3
5	-14.7	-6.2	16.0
6	-7.6	-15.2	17.0
7	-5.2	-5.3	7.4
8	-23.1	57.8	62.3
9	30.8	-37.7	48.7
avg:	0.0	0.0	26.9
rms:	18.2	26.2	31.9

With average residuals of nearly 27 pixels among the nine control points, the linear transformation was deemed insufficient for the rectification process. Nevertheless, the transformation would provide a good initial estimate for the non-linear sensor model used in the final rectification.

¹ For numerical stability, the nine values of the coordinates (x, y) and (X, Y) were shifted and scaled to the range $[-1, 1]$ before computing the transform (for example, $x' = x_{scale}(x - x_{shift})$ such that $-1 \leq x' \leq 1$ for all x').

4.5 Non-Linear Sensor Model

A non-linear orbital model for a “push broom” sensor was adopted to more correctly model the QuickBird sensor. This model included six typical Keplerian orbit parameters: semi-major axis— a , eccentricity— e , inclination— i , longitude of ascending node— Ω , argument of perigee— ω , and time of image’s center line (relative to time at ascending node)— t_f . It also included the average time per line and optical principle distance. Finally, the model allowed for up to second-order, time-varying adjustments in the sensor position (Cartesian coordinates relative to the earth-centered-earth-fixed system: X_{ECF} , Y_{ECF} , Z_{ECF}) and attitude (Euler angles; ω , ϕ , κ , about the sensor’s principle axes; x , y , and z ; respectively). These latter parameters were applied in the following manner:

$$p' = p + \delta p_0 + \delta p_1 \cdot \Delta t + \delta p_2 \cdot \Delta t^2$$

where p' is an adjusted position or attitude value, p is an unadjusted position or attitude value, δp_i are the model’s adjustment parameters for the corresponding position or attitude values, and Δt is the time offset from the collection time for the image’s center line.

4.6 Image Resection

Using the non-linear sensor model and ground control points described above, the original image was resected, providing refined values for each of the model parameters. These resection values are given in Table 4.3. These values were those used in the image rectification. The residuals for the nine control point measurements using the refined model values are provided in the second table. These residuals are approximately three times smaller than those obtained with the linear model, and are well within the accuracy of the surveyed ground control points (approximately, 13 pixels 1σ).

Table 4.3 Resection Values

Param	Value
a	6823930.710822498 m
e	0.00100437216846
i	1.69646003306536 rad
Ω	1.69905118058213 rad
ω	1.43729969504013 rad
t_f	2178.589515811723 sec
t_i	1 / 6900 sec
PD	8836.202mm / 0.01191396mm/pix
δX_0	19.96368408097603 m
δX_1	0.14836093241336 m/s
δX_2	0 m/s ²
δY_0	-93.92935587220913 m
δY_1	-3.65126508130803 m/s
δY_2	0 m/s ²
δZ_0	82.19849966882340 m
δZ_1	1.93381385402477 m/s
δZ_2	0 m/s ²
$\delta \omega_0$	-0.09690797913937 rad
$\delta \omega_1$	0.00222552371876 rad/s
$\delta \omega_2$	-2.405903376547046e-006 rad/s ²
$\delta \phi_0$	-0.03791121640411 rad
$\delta \phi_1$	0.00665718337752 rad/s
$\delta \phi_2$	1.524874442971182e-005 rad/s ²
$\delta \kappa_0$	0.15614532407029 rad
$\delta \kappa_1$	-8.146627170113382e-004 rad/s
$\delta \kappa_2$	-5.822007773405202e-004 rad/s ²

Cntrl Pnt	Residuals in Pixels		
	x	y	radial
1	4.9	1.9	5.3
2	-0.3	-4.2	4.2
3	1.0	3.1	3.2
4	-10.1	-0.6	10.1
5	-11.4	-0.6	11.5
6	3.8	-2.3	4.5
7	20.3	4.2	20.7
8	-11.7	-1.4	11.8
9	3.5	-0.1	3.5
avg:	0.0	-0.0	8.3
rms:	9.6	2.5	9.9

The values for the orbit parameters were obtained from published standard orbit descriptions for the QuickBird satellite (as is the case for inclination and period), from the image support data (a single orbit position at a specific time was used), and from the NORAD space tracking data available via the internet at (<http://celestrak.com/NORAD/elements>). This latter source was used to obtain the values for eccentricity and the argument of perigee. The time at center line collection was computed using the previously discussed orbit parameters, the UTC time for the first line collection (provided with the image), and the average time per line (also provided with the image). The refined model with the resection parameters above offered sufficient accuracy to proceed with the mapping of the image to the rectification grid. The resection accuracy would be improved with a more accurate ground control point survey.

4.7 Rectification Grid

To have all the data used in the project be in the same coordinate system a UTM-coordinate grid was established to capture the area of interest. This grid had a step size of 0.6 m in both the north and east directions. The grid covered from 552,300 to 559,500 m in Easting and 4,389,700 to 4,394,800 m in Northing (UTM zone 16)— an area of 7.2 km by 5.1 km. This grid would result in an image of 12000 by 8500 pixels.

4.8 Image Rectification

For an element of the rectification grid, the corresponding image coordinate had to be determined using the refined non-linear sensor model. This calculation required an initial image coordinate estimate (determined using the linear transformation discussed above). The approximated image line could then be used to estimate the time of collection. Using the sensor model, the gradient for the error surface near the estimate was determined. The two-dimensional gradient was then used to solve for a final image coordinate (x, y) corresponding to the grid element (X, Y) . The gray-level value for the rectified grid pixel was then determined by interpolating (a bilinear interpolation scheme was used) between the gray values for the nearest four pixels in the original image. These steps were repeated for each of the 102 million pixels in the rectification grid.

4.9 Potential Improvements

The following items are for consideration for future improvements upon the process outlined in this chapter:

- A high accuracy survey of ground control points within the image. This should include points distributed throughout the image (such as the existing points) and could include additional points near the area of interest. All points must be recognizable and unambiguous in the QuickBird image.
- Modification of the available TIFF tools to accept 16-bit images and to interpret GeoTIFF tags.
- Modification of the sensor model to allow parameter adjustments along the orbit axes rather than in the ECEF frame.
- Modification of the sensor model to use ephemeris data provided with the image.

- Allowance for rectification using the rational polynomial coefficients provided with the image.
- Error propagation calculations for each of the above models.

CHAPTER 5 Control

To enable to put the lidar survey “on the map”, the three dimensional coordinates of a sufficient number of well identifiable points in the (combined) Lidar point cloud had to be determined. This absolute orientation, to use photogrammetric terminology, was performed in a two step process. Section 5.1 describes how horizontal coordinates were brought to the Bridgeport Bridge by a GPS survey via horizontal control as provided by NGS control points in the vicinity of the project. A local survey using a total station (section 5.2) completed the absolute orientation in horizontal and vertical sense. Appendices C and D give more a more detailed background of the GPS survey and total station survey, respectively.

5.1 Global Positioning System (GPS)

Introduction

GPS is a radio-navigation system developed by the Department of Defense. It is a worldwide space-based system that consists of fully operational 24 satellites orbiting the earth in six circular orbits at an altitude of 20200 km. As its name indicates, its major function is to pinpoint 3D locations using specially manufactured receivers.

Because of the availability of many local, regional and global reference frames, the decision has been made to use the GPS technology to get points on Bridgeport bridge and Six Point bridge in its reference frame: World Geodetic System 1984 (WGS84). When combined with classical topographic survey of several other points on both bridges, this will make it possible to transform the bridges to other reference frames, like State Plane Coordinate System.

Preliminary Preparation

In order to be able to measure the positions of the points on the bridges with high accuracy, the decision was made to occupy few control points that have their positions accurately determined by the National Geodetic Survey (NGS): www.ngs.noaa.gov. Four points in the neighborhood were selected. The Permanent Identifiers (PID's) of these points are: KA0140, KA0159, KA1653, KA1958, and they are shown in Figures 5.1-5.4 below. Although many other NGS control points are available, as seen in Figure 5.5, but the selection was made such that these control points and the points on the bridges can be occupied simultaneously. This made the selection takes into consideration the accessibility to these control points and the distances from and to them, all along with nature of these points and whether they provide horizontal control only or control in 3D. The details of the horizontal and vertical characteristics of these points are listed in Table 5.1 below. Using the info given in NGS datasheets, the map shown in Figure 5.6 is created in ArcMap (ArcGIS) showing the control points, the Bridgeport Bridge and Six Points Bridge. The images used in the background are the aerial orthophotos of the area, acquired from the CAAGIS website (<http://pasture.ecn.purdue.edu/~caagis/>).

Figure 5.1: Map of KA0140

Figure 5.2: Map of KA0159

Figure 5.3: Map of KA1653

Figure 5.4: Map of KA1958

Figure 5.5. Control points around the project area and the bridge locations.

Table 5.1: Order of Control Points (source: www.ngs.noaa.gov)

PID	Horizontal	Vertical
KA0140	Order B (second best)	Unknown Stability
KA0159	Order B (second best)	Order 2 (second best)
KA1653	Order B (second best)	Order 1 (the best)
KA1958	Order 1 (third best)	Unknown Stability

Figure 5.6. The selected control points around the project area and the bridges.

Reconnaissance Trips

In order to assure that these control points are still in their positions in good condition and easily accessible, two reconnaissance trips were done to the area. The first trip was done on Sunday, September 22, 2002, 12:45 PM – 03:30 PM. Point KA0140 (designator: Mills Reset) was easily accessed and was in good condition, as shown in Figure 5.7.

Figure 5.7: NGS Control Point: KA0140 (Mills Reset)

Approximate GPS coordinates were measured with a hand-held GPS receiver, as shown in Figure 5.8, and the coordinates confirmed that this is indeed the point needed. This was done with all other control points too.

Figure 5.8: Measurement of Approximate Coordinates of KA0140

After that, point KA1653 (designator: F 350) was visited and proved to be easily accessible and was in acceptable condition, as shown in Figure 5.9.

Figure 5.9: NGS Control Point: KA1653 (F 350)

The second recon trip was carried out after the Cyrax laser scan was completed, on Thursday, September 26, 2002, 04:00 PM – 05:30 PM. First, point KA0159 (designator: C 64) was visited and it proved to be in good condition and easily accessible, as seen in Figures 5.10 and 5.11 below.

Figure 5.10: NGS Control Point: KA0159 (C 64)

Figure 5.11: Easy Accessibility to Point KA0159

Finally, point KA1958 (designator: Plain) was visited. It was a challenge to find the point because it was buried under mud and leaves in a hole. Also, there was another North marker next to it, which could be confused with it. After cleaning the hole from the leaves and removing the mud, the point appeared in good condition as seen in Figures 5.12 and 5.13 below.

Figure 5.12: NGS Control Point KA1958 (Plain)

Figure 13: Point KA1958 in the Hole

While the cleaning was done, armed guards came asking about what is going on. It was learnt later on that the Indiana Youth Center seen in Figure 5.4 is nothing but a rehabilitation center for youth prisoners. We have been instructed to let them know when we come back to carry out the GPS survey. As this was taken care of, the accessibility to this point proved later on to be easy.

Using Figure 5.14 below, the GPS survey has been planned as shown in Table 5.2.

Table 5.2: GPS Survey Design

	8:00		8:30	9:10		9:40	10:20		10:50	11:30		12:00	13:00
		Session 1			Session 2			Session 3			Session 4		
R1		KA0140			KA1653			KA1653			KA0140		
R2		BPB-C			BPB-C			6PB-J			6PB-J		
R3		BPB-A			KA1958			KA1958			6PB-H		
R4		BPB-F			KA0159			KA0159			6PB-M		
<div> <div>KA0140-KA1653</div> <div>7.1 MILES</div> <div>14 min with 30mph</div> </div> <div> <div>BPB-6PB</div> <div>2.1 MILES</div> <div>4.3 min with 30mph</div> </div> <div> <div>BPB-KA1958</div> <div>7.3 MILES</div> <div>15 min with 30mph</div> </div> <div> <div>KA1958-6PB</div> <div>7 MILES</div> <div>14 min with 30mph</div> </div> <div> <div>BPB-KA0159</div> <div>7.4 MILES</div> <div>15 min with 30mph</div> </div> <div> <div>KA0159-6PB</div> <div>6.7 MILES</div> <div>13 min with 30mph</div> </div>

Figure 5.14: Design map with paths between the points showing the distances

The GPS Survey

The GPS survey was carried out on **11th Nov 2002**. The survey was accomplished in four sessions and each session consisted of occupying a point for a period of half an hour. During each session, four stations were occupied simultaneously, of which one station was a known station. Table 5.3 shows the occupation of the stations and their corresponding sessions. Four GPS receivers were used for this survey, denoted by R1, R2, R3, and R4. During the survey, six unknown points, three on **Bridgeport Bridge** and three on **Six Points Bridge** were occupied and four known points, **KA0140**, **KA0159**, **KA1653** and **KA1953** were occupied. While planning the survey, the times of occupation at each session were decided on and they are shown in Table 5.3. However, the survey team encountered some problems during the first session. The receiver on station BPB-F lost the lock on satellites. This forced us to change the time of the sessions accordingly.

Session #1: Time 8.30-9.00 A.M. The stations occupied were KA0140 and the points denoted as BPB-C, BPB-A and BPB-F. The last three points denote the points on the Bridgeport Bridge.

Figure 5.15: Bridgeport Bridge

Table 5.3 GPS Survey Stations and Sessions

	8.30-9.00	9.40-10.10	10.50-11.20	12.00-12.30
Receiver	Session 1	Session 2	Session 3	Session 4
R1	KA0140	KA1653	KA1653	KA0140
R2	BPB-C	BPB-C	6PB-J	6PB-J
R3	BPB-A	KA1958	KA1958	6PB-H
R4	BPB-F	KA0159	KA0159	6PB-M

The station labeled BPB-C is the Indiana Department of Transportation Bench Mark **G-163**. The receivers R2, R3 and R4 occupied the stations on the Bridgeport Bridge, while the R1 occupied the control point KA0140.

Figure 5.16 GPS Survey

Figure 5.17 GPS Survey

Session #2: Time 9.40-10.20 A.M. The receiver R1 was taken to station KA1653 and receivers R3 and R4 occupied stations KA1958 and KA0159 respectively. The receiver R2 was kept at the point BPB-C.

Session #3: Time 10.50-11.20 A.M. The receiver R2 was moved to station 6PB-J, which was on the **Six Points Bridge**. The other receivers occupied the same positions as in Session 2.

Figure 5.18 : Six Points Bridge

Session #4: Time 12.00-12.30 P.M. The receiver R1 was taken back to station KA0140 and receivers R3 and R4 occupied stations 6PB-H and 6PB-M respectively. The receiver R2 occupied the same station as in Session 3, i.e. 6PB-J.

The GPS survey took 4 hours from start to finish, getting the necessary control on the two bridges.

Processing the Data

The GPS data collected in the field was imported and processed by software called *Pinnacle*. It was imported easily. After deletion of few erroneous measurements, the data looked like this:

Figure 5.19: Occupation View

After that initial data clean-up, various network pre-adjustment tests were done, and they all passed well. These tests were: Subnet/Solution input data validation, Network Structure Test, and Loop Misclosure and Repeated Vectors. After that, the network was adjusted only with Inner Constraints: Free Network Adjustment, to test the inner consistency of the measurements and adjustment results. The results were very good as error ellipses of points never exceeded 1 cm and the network looked like Figure 5.20 below.

Figure 5.20: Free Network Adjustment Results

Zooming in Bridgeport Bridge and Six Point bridge reveals the view seen in Figure 5.21 below.

Figure 5.21: Area of Pilot Project

After that, NGS datasheets were attached to respective points to make use of the control information in them, and the network was adjusted using various Weighted and Fixed Modules in the North American Datum 1983 (NAD83), which is closely related to WGS84. The best adjustment results were acquired with the Weighted Module with minimum error of 2.1 mm and maximum error of 6.7 mm in the points sought, as seen in Table 5.4 and Figures 5.22-5.23 below.

Table 5.4: Final Results of Adjusted Coordinates in NAD83

ID	Pinnacle Name	Latitude	Longitude	height(m)	s(N)	s(E)	s(U)
KA0140	rec1_4521	39°42'16.98646"N	86°15'29.31895"W	197.5604	0.2	0.2	4.9
KA1653	rec1_4521_S2	39°45'51.75539"N	86°18'09.38069"W	204.9889	0.2	0.2	5.2
BPB-C	rec2_2656	39°41'21.85450"N	86°19'13.03939"W	201.7783	2.1	1.8	5.9
6PB-J	rec2_2656_S5	39°40'57.22863"N	86°20'09.18901"W	192.0132	2.3	2.1	6.7
BPB-A	rec3_1947	39°41'20.49997"N	86°19'12.06519"W	201.8801	2.2	1.8	6.1
KA1958	rec3_1947_S1	39°41'29.33961"N	86°25'06.45938"W	207.4593	3.1	2.9	8.3
6PB-H	rec3_1947_S3	39°40'55.18700"N	86°20'09.16070"W	192.1224	2.3	2.1	6.6
BPB-F	rec4_2341_S1	39°41'20.10279"N	86°19'12.14378"W	201.7890	2.1	1.8	6.1
KA0159	rec4_2341_S2	39°37'11.68783"N	86°21'43.96842"W	172.6206	3.0	2.8	4.9
6PB-M	rec4_2341_S5	39°40'54.85157"N	86°20'09.47523"W	192.0173	2.3	2.1	6.6

Figure 5.22: Bridgeport bridge

Figure 5.23 Six Point bridge

This step concludes the processing of GPS data.

Usage of GPS-calculated coordinates

The NAD83 coordinates are easily converted to State Plane Coordinate System or UTM within *Pinnacle* itself. This data has been combined with topographic survey on each bridge, linking three more points to the three GPS-calculated points. Thus, six points with known coordinates have been acquired on each bridge.

Using these six control points on each bridge, point clouds acquired with laser scanning technology can be registered to any desired coordinate system. After that, many applications can be done. These point clouds can be modeled in 3D in real world coordinates. They can be overlaid on space imagery. They can be overlapped on MXRoad point cloud and quantitative comparisons can be carried out. They can be exported to the GIS technology for various processing. The crucial achievement of the GPS survey is to have the extremely intense point clouds (millions of points) captured by the laser scanner in a familiar coordinate system that facilitate any real world visioning or processing or measurements. Various applications of laser scanning and GIS are detailed in their respective chapters.

Linking GPS Survey to Topo-Survey

During the process of scanning the bridge using Lidar, six spheres were used as objects which could provide control for registration of the scans and also for converting the coordinates of the point cloud from the Lidar system to Geographic coordinates. The coordinates of three of these spheres could be directly determined from the GPS survey that has been described in the previous sections. To bring control to the other three spheres on the bridge, a Topo survey using Total station was carried out, and the data was adjusted using the Move3 Program. This process is described in the next section

Total Station Survey

The total station survey was carried out to link three points that were surveyed using GPS to the other three points on the bridge.

Figure 5.24: Layout of Points on the Bridgeport Bridge

The points A, B, C, D, E and F are points on the bridge where the spheres were placed during the Lidar survey for the internal registration of the various scans. To convert the coordinates of the Lidar point cloud that were generated during the scan to UTM or other coordinate systems, the points A, C and F were surveyed using GPS. The other three points were geo-referenced using a Total Station Survey.

A Topcon GTS-310 series Electronic Total Station instrument was used for this purpose. The Survey data, along with the GPS results were then analyzed in the MOVE3 software program for data adjustment.

Figure 5.25 Total Station Survey

Figure 5.26 Total Station Survey

5.2 Data Processing

5.2.1 Processing the Data in MOVE3

The survey data was input in the Move3 software package along with the GPS data which was taken as control. The adjustment was performed in three different coordinate systems, namely the Geographic (Latitude, Longitude, and Height), UTM North, Zone 16 and the State Plane coordinate system (SPCS). The Pinnacle software was initially used to convert the Lat/Long coordinates of the three points to the UTM and SPCS. The Pinnacle uses the latest NAD 83-1997 datum and when registration on the Lidar Scan was performed and compared with a dataset obtained from Indiana Department of Transportation, they were off by 0.8 meters in the North and 0.4 meters in East. This was due to the difference in the NAD83 and the NAD 83-1997 ellipsoids.

MOVE3®

The coordinates obtained from the GPS survey for three points on the bridge was integrated with the Total Station Survey using the **MOVE3**® version 3.1.1 software. This gave us the coordinates of six points on the bridge where Spheres had been placed during the Lidar Scan.

The mathematical model applied in **MOVE3** [©] is rigorously ellipsoidal, independent of the dimension of the solution. In essence an ellipsoid is a curved 2D surface. The third dimension is introduced by defining heights above the ellipsoid. The software allows the user to either work in Geographic Latitude, Longitude and height, or if the projection is known, the user can use coordinates in a Map Projection. In that case the adjusted coordinates will be output in the same projection, thus conveniently hiding the ellipsoidal model from the user.

For the adjustment process, there were 81 observations including 24 direction observations, 24 distances, 24 Zenith angles and 9 coordinates from the GPS survey. The unknowns were the coordinates of the 6 points, orientation unknowns and scale factor.

In Move3, three Statistical tests are carried out by implementing the F-Tests, W-Tests and the T-tests.

The F-Test

The F-test is a very commonly used multi-dimensional test. The F-test is often called the overall model test, because it tests the model in general.

The F-value is given by the expression:

$$F = s^2 / \sigma^2$$

Where

s^2 = a-posteriori variance factor, depending on the computed residuals and the redundancy.

σ^2 = a-priori variance factor.

The F-value is tested against a critical value of the F-distribution, which is a function of the redundancy and the significance level α . The F-test can be rejected either due to gross errors, incorrect mathematical model or an incorrect stochastic model. The information

provided by the F-test, namely acceptance or rejection of the null-hypothesis is not very specific. Therefore if the test is rejected, it is necessary to find the cause of the rejection by tracing errors in observations or assumptions. A gross error in the observations will then be revealed if a rejected F-Test is followed up by a W-Test. In our case, The F-test was accepted at 0.048 (The ratio s^2 / σ^2), against a critical value set at 1.10 (default value in Move3).

A bug in the MOVE3 program prevented us from using the WGS84 ellipsoid that was listed in their Pull down menu. This problem was a trivial one and was solved by using the User defined ellipsoid and giving the parameters of the WGS84 ellipsoid as the input. The program needed approximate coordinates for all the six points that were being adjusted. Since three of the coordinates were known coordinates, obtained from the GPS survey, an in-built COGO program calculated the approximate coordinates for the other 3 points.

Depending on the Input coordinates, the Adjustment output can be either in Geographic Lat/Long or in a Map Projection system (e.g. SPCS or UTM). In the latter case, the Projection needs to be defined before carrying out the adjustment process.

5.2.2 The Adjustment

The adjustment process in Move3 is a two step process. The first step is termed the *Free Network adjustment*. In a free network adjustment, the geometrical layout is determined by the observations only. The position, scale and orientation of the network are fixed by a minimum number of constraints, through the base stations. Thus, the base stations impose no extra constraints on the adjustment solution. The free network adjustment verified the quality of the observations.

After the Free Network adjustment, we can either chose a Constrained adjustment, in which case even the Base station coordinates (The Points surveyed using GPS) will

receive corrections or the Absolute Constrained Adjustment, which does not change the Base station coordinates.

In our case, we used the Absolute adjustment process to obtain the coordinates of the three unknown points.

The Adjustment Results are attached in Appendix D. The coordinates obtained for the 6 points on the Bridge in the Three systems are summarized in Tables 5.5, 5.6 and 5.7.

Table 5.5: Results of Adjustment in Geographic Coordinates

Point Name	Latitude	Longitude	Height(NAVD 88)
A	39 41 20.5000	86 19 12.0652	201.8801
B	39 41 21.0708	86 19 12.4799	201.9368
C	39 41 21.8545	86 19 13.0394	201.7783
D	39 41 21.5293	86 19 13.1748	201.6516
E	39 41 20.8231	86 19 12.6633	201.9376
F	39 41 20.1034	86 19 12.1437	201.7890

Table 5.6: Results of Adjustment in UTM Coordinates

Point Name	Easting	Northing	Height(NAVD 88)
A	558305.7441	4393464.2296	201.8801
B	558295.7374	4393481.7464	201.9368
C	558282.2237	4393505.8131	201.7783
D	558279.0704	4393495.7632	201.6516
E	558291.4249	4393474.0734	201.9376
F	558303.9650	4393451.9706	201.7890

Table 5.7: Results of Adjustment in State Plane Coordinates

Point Name	Easting	Northing	Height(NAVD 88)
A	965475.3293	493269.5678	201.8801
B	965465.3026	493287.0820	201.9368
C	965451.7614	493311.1452	201.7783
D	965448.6162	493301.0886	201.6516
E	965460.9955	493279.4021	201.9376
F	965473.5608	493257.3025	201.7890

5.2.3 Ellipsoidal Heights to Ortho-metric Heights

The heights in the three tables are ellipsoidal heights and these were used throughout the Adjustment process because the Geoidal undulation for all the 6 points was a constant of -32.995 meters in the GEOID96 system and -33.005 meters in the GEOID99 system. The ellipsoidal heights were then converted to Orthometric heights. These coordinates were then used to register the Lidar point cloud in the real world system of coordinates.

CHAPTER 6 Geographic Information System (GIS)

Simply put, a GIS combines layers of information about a place to give you a better understanding of that place. What layers of information you combine depends on your purpose—finding the best location for a new store, analyzing environmental damage, viewing similar crimes in a city to detect a pattern, and so on.

The old adage "better information leads to better decisions" is true for GIS. A GIS is not just an automated decision making system but a tool to query, analyze, and map data in support of the decision making process.

One of the main benefits of GIS is improved management of your organization and resources. A GIS can link data sets together by common locational data, such as addresses, which helps departments and agencies share their data. By creating a shared database, one department can benefit from the work of another—data can be collected once and used many times.

A full GIS, or geographic information system, requires:

- Hardware (computers and peripherals)
- Software
- Data
- People
- Training

and sound analysis methods for interpreting the results generated by the GIS.

6.1 Introduction

This report presents the methodology of creating a geo-referenced 3D model and visualization of project area. In order to do this, aerial images (DOQ), satellite photos, digital elevation model (DEM), lidar data, and the MxRoads data are used. Over the orthorectified aerial and satellite photos the MxRoads data and the lidar data of the Bridgeport bridge are extruded using a DEM as the base terrain. The model can be queried and navigated from ArcScene and ArcMap environment, the tools of ArcGIS software.

Three-dimensional GIS is an area of GIS that developed recently. The applications are varied: creating 3D maps that represent better features or processes with a third dimension (terrain, buildings, etc.), for appealing presentations, creating virtual models that can be navigated and queried (relief maps for tourist use, city planning, transportation, architecture, archeology).

In this project a virtual model for the project area is created. A high-resolution satellite photo (Quickbird) is orthorectified using the DEM for the area, and is used to give the real appearance to the model. National Elevation Dataset (NED) DEM assembled by the U.S. Geological Survey is used as the base terrain for the MxRoads and lidar data.

6.2 Data

Figure 6.1. A part of the DOQs showing the project area.

The geographic extent of the digital orthophoto (DOQ) is equivalent to a quarter-quadrangle (3.75 minutes of latitude and longitude), plus 50 to 100 meters of overlap. Each image covers roughly 10,000 acres and each photo is compressed from

approximately 50 megabytes to 5 megabytes. The uncompressed resolution is 1 meter. Resolution is the minimum distance between two adjacent features, or the minimum size of a feature that can be detected by a remote sensing system. The quality of the image is slightly degraded due to the compression in MrSID. The projection used for these photos is Universal Transverse Mercator (UTM). The datum is the North American Datum of 1983 (NAD83), with coordinates in meters. The uncompressed orthophotos conform to National Map Accuracy Standards at the scale of 1:12,000. This means that 90 percent of the well-defined points tested must fall within 33.3 feet (1/30 inch at the original scale) of their actual position. The compression may degrade this slightly. The images are developed from aerial photos taken in 1998, with some from 1999. The 24 DOQs (Figure 6.1) used in this project are downloaded from Center for Advanced Applications in Geographic Information Systems (CAAGIS) website (<http://danpatch.ecn.purdue.edu/~caagis/ftp/gisdata/data.html>).

The National Elevation Dataset (NED) is a new raster product assembled by the U.S. Geological Survey. NED is designed to provide National elevation data in a seamless form with a consistent datum, elevation unit, and projection. Data corrections were made in the NED assembly process to minimize artifacts, perform edge matching, and fill sliver areas of missing data. NED has a resolution of one arc-second (approximately 30 meters) for the conterminous United States, Hawaii, and Puerto Rico and a resolution of two arc-seconds for Alaska. NED data sources have a variety of elevation units, horizontal datums, and map projections. In the NED assembly process the elevation values are converted to decimal meters as a consistent unit of measure, NAD83 is consistently used as horizontal datum, and all the data are recast in a geographic projection. The NED data (Figure 6.2) in UTM is acquired from the GIS lab at Purdue University Civil Engineering Department, Geomatics Engineering Program. The data covers an area of 905 square kilometers and is 4.4 MBs. Other than NED DEM InfSAR DEMs can also be used but currently no InfSAR data is available for the project area.

Figure 6.2. NED DEM data for the project area.

The satellite photo (Quick Bird imagery) used in the project is a product of DigitalGlobe company. QuickBird Imagery Products are available in three different product types.

- Basic Imagery is the least processed of the QuickBird product suite and is corrected for radiometric distortions, internal sensor geometry, optical distortions, and sensor distortions. Basic Imagery is neither geo-referenced nor mapped to a cartographic projection. Basic Imagery is provided with the QuickBird sensor model and is intended for sophisticated photogrammetric processing such as orthorectification. Basic Imagery is a scene-based product, meaning that it can only be ordered in scene increments. Basic Imagery is available as either black and white or multispectral products.

- Standard Imagery is a geo-referenced product, which is radiometrically calibrated, corrected for sensor and platform-induced distortions, and mapped to a cartographic projection. Standard Imagery is provided with image metadata and is intended for a wide variety of applications. Standard Imagery is an area-based product, meaning that the product is defined by your area of interest without reference to scenes. Standard Imagery is available as either black and white, multispectral, color, or pan-sharpened products.
- Orthorectified Imagery is a terrain corrected product, which is radiometrically calibrated, corrected for sensor and platform-induced distortions, and mapped to a cartographic projection. This product is GIS-ready and can be used as an image base map for a wide variety of applications where a high degree of absolute accuracy is required. Orthorectified Imagery is an area-based product, meaning that the product is defined by your area of interest without reference to scenes. Orthorectified Imagery is available as either black and white, multispectral, color, or pan-sharpened

QuickBird Imagery used in the project is a Basic product which has a spatial resolution of 61 cm taken on January 15, 2003. The imagery is orthorectified and stored in UTM NAD83 coordinate system. The size of the imagery is approximately 1.6 GB which covers 307.6 square kilometers. For the purpose of the project only the portion covering the project area is used which is 100 MB and covers 36.72 square kilometers (Figure 6.3).

Figure 6.3. A portion of the satellite photo showing the project area.

The MXROAD data used in the project is provided by INDOT (Figure 6.4). The data is in a local coordinate system. A quick description of the MXROAD software and the data for the project area, and the data format is also provided by the INDOT personnel. Two people from the project team also attended a short course on MXROAD in Indianapolis. MXROAD is a computerized tool for rapid and accurate design of all types of road project. It combines the string modeling with traditional design methods.

MXROAD is part of a fully integrated family of cost effective applications, offering an interoperable database in Windows, AutoCAD and MicroStation environments. It is designed to operate with a String naming convention enhancing automation and standardization.

With MXROAD the following operations can be done:

- Input all data and perform analysis
- Design with dynamic 3D alignment techniques, including transitions
- Access to full alignment functionality with element and P.I. methods
- Apply user definable carriageway and shoulder styles to 3D center lines
- Automate application of superelevation and checking to local standards
- Design roadway widening for extra lanes, turnouts or intersections
- Automate intersection design
- Design earthworks
- Interactive editing of cross sections
- Design specialized pavement layers
- Calculate volumes
- Produce drawing and visualisation (<http://www.infrasoft-civil.com>)

Figure 6.4. MXROAD data used in the project.

The processed lidar data is also converted into UTM using the control points on the bridge, again using a Matlab script. The lidar data shown in Figure 6.5 is a 2% reduced portion of the original data. Although the best way to show the data is a model of the

bridge delineated from the lidar data currently it is not easy to perform such type of feature extraction from this data.

Figure 6.5. Lidar data showing the bridge.

Since the aim of the project is evaluation of the recently developed and improved methods to collect or use geospatial data the best way to show all of these is a GIS environment in which one can show all sorts of data regardless of their coordinate systems and their format.

6.3 Methodology

6.3.1 Data Processing

The first step is the conversion of the MXROAD data into a suitable format for the used GIS software (ArcGIS). After investigation of the MXROAD and the ArcGIS no direct way is found to convert the data. Therefore the data is converted to a DXF file. Originally

the MXROAD data consists of strings which describe the data for the software. When the data is converted to DXF it has point, text, and line features in it. To preserve the 3rd dimension of the features and to use them appropriately in ArcGIS the DXF file is converted to a proper text file which can be imported into ArcGIS. The conversion is done by writing a script in Matlab software. Although the ArcGIS can show all data in different coordinate systems at once, the data is converted into UTM NAD83 coordinate system to prevent any misinterpretation of the data. The conversion is done by using the control points used in GPS analysis which are given in the documentation (Appendix C) provided by the company that produced the MXROAD data. ArcGIS allows users to keep the metadata information with the data itself. This ability provides the status of the data, time period for which data is relevant, publication information, spatial data description, and the description of the attributes of the data.

The lidar data processed by the Cyclone software is reduced to a 2% of the original one to visualize the data faster in ArcGIS, converted into UTM and imported as a shapefile.

The satellite imagery is also rectified in UTM and saved as “satimagery.tif” which can be found in the provided CDrom.

Figure 6.6 shows the data used in the project all together in one view.

Figure 6.6. The data used in the project

6.3.2 3D Modeling and Analysis

To create the 3D model the NED DEM is used as the base terrain and the rectified satellite photo, the MXROAD data, Lidar points, DOQs are draped over the terrain

The 3D model is constructed in ArcScene (Figure 6.7). 3D Analyst™ is the three-dimensional (3D) visualization and analysis extension to ArcGIS™. 3D Analyst adds a specialized 3D viewing application, ArcScene™, to your desktop, and extends ArcCatalog™ and ArcMap™ so that one can more effectively manage his/her 3D GIS data, do 3D analysis, and edit 3D features. 3D Analyst lets interactive query of the values in a raster surface and the elevation, slope, and aspect of TINs.

The vector files lidar data and the MXROAD data can be queried. The type of the MXROAD string can be found the coordinates of the lidar points can be queried or the distance between two points can be measured easily. The 3D properties of the scene allow specifying a vertical exaggeration factor that makes the 3D effect more visible. Also the sun elevation and azimuth can be modified to give the desired lighting effect. ArcScene allows the selection of image resolution (up to full resolution).

Figure 6.7. 3D Model showing the MXROAD data, DOQs, satellite imagery and the DEM.

Figure 6.8. MXROAD data can be queried in ArcScene environment.

Figure 6.8 shows one of the query tools of ArcScene which shows the type of the selected MXROAD feature.

ArcScene provides the ability to create, save, and share animations. One can create animations in different ways, composing the animation of multiple tracks that animate the scene properties, a layer, or the camera. An animation may be saved in a scene document, as an independent ArcScene Animation (*.asa) file, or exported to an *.avi file. One can share animations by exchanging scene documents, interchanging *.asa files, or distributing *.avi files.

Animations make scene come alive by storing actions so they can be replayed as it is chosen. They can help you visualize changes in perspective, changes in the scene's properties, geographical movements, and temporal changes.

To show these capabilities a small animation file is created and put into the CDrom provided as “FLYTHROUGH.AVI”.

The 3D scene can also be saved as a VRML file which can be viewed in an Internet browser.

The DOQ images are used for the preliminary phase of the GPS analysis. The control points that will be visited are put on the DOQ images and the field trip is planned accordingly. That helped a lot before visiting the area.

To see the difference between satellite imagery and the DOQs Figure 6.9 is created for the same extent. As known before the DOQs are produced almost five years ago and the satellite imagery is taken in 2003, production time is much longer than getting a satellite imagery and the resolution of the satellite imagery is better than DOQs. Figure 9 shows how much the scene has changed after five years.

Figure 6.9. Comparison of the DOQs (left) and the satellite imagery (right).

6.4 Results

Using satellite imagery instead of aerial photos can provide faster results to investigate the project area.

Conversion of the MXROAD data into the ArcGIS system is not easy, but it is hoped that this problem can be solved very easily. The lidar point cloud should be processed and a CAD model of the data should be obtained to obtain more useful information.

Surveyors and engineers understand the importance of geographic data. Surveyors use precise instruments, procedures, and computations to accurately locate and define geographic features while conducting field surveys that range from cadastral to engineering construction layout. Engineers design and build structures and infrastructures on geography measured by surveyors.

A GIS provides tools to help surveyors integrate a variety of data sources and types, maintain and manage inventories, visualize data and related information using dynamic maps, make decisions about resource management, and perform modeling and analysis. The expansion of GIS technology has led to the development of new tools created specifically for surveyors and engineers.

GIS can be used to determine the location of an event or asset and its relationship or proximity to another event or asset, which may be the critical factor leading to a decision about design, construction, or maintenance. The cost of feature maintenance and asset inventory creation may be significantly reduced through the use of automated data collection and software tools

GIS helps organize bridge management information contained in various forms, such as inspection reports, rehab plans, and CAD files. Maintenance management and asset valuation may be enhanced with GIS and linear referencing systems.

CHAPTER 7 Conclusions

Design data collection involving the use of Lidar instrument, in conjunction with GPS proves to be a very effective. Data required to model two bridges was collected on a single day, involving five-six sessions with the instrument. Even though the data was collected on two bridges over the I-70, it did not cause any disruption of the traffic, either on the Interstate or on the bridges. A major cause of concern during such activities, particularly along interstates can be safety, both for the motorists as well as the people involved in data collection. Lidar data collection was found to be extremely safe in both these respects.

The whole process of collecting the Lidar data and the GPS coordinates for control was completed in 2 days for both the bridges. Office work involved combining the GPS data with conventional survey data to bring control on six pre-selected within the lidar point cloud. This control information was later used to bring the point cloud to a geographic coordinate system.

This provided us with means to compare the 3D point cloud with the bridge designs that were created using other methods of data collection. It was found that the 3D point cloud exhibits a very high degree of accuracy, both internally and also when geo-referenced independently using GPS and conventional control survey. The lidar model was also compared to the MXRoad data model provided by INDOT. The discrepancies between the two models were not larger than 0.125 ft/3.81 cm and 0.05 ft/1.52 cm in the horizontal and vertical planes respectively.

The data collected could completely model the bridge and the accuracy of the data ensures that any models of the bridge, either as a whole or in part, will correctly reflect the current state of the bridge.

As shown in section 3.6, the data collected can be used for various applications including cut-and-fill estimates, modeling the state of the bridge, making measurements on various parts of the bridge etc.

A cause of concern is the amount of data involved. As millions of 3D points are collected, popular CAD/GIS packages are unable to deal with it. For this reason proprietary software, designed particularly to handle such huge volumes of data involved, was used for analyzing this data. However, it is possible to export data from this software to other commonly used CAD packages.

Using satellite imagery instead of aerial photos can provide faster results to investigate the project area.

Conversion of the MXROAD data into the ArcGIS system is not easy, but it is hoped that this problem can be solved very easily. The lidar point cloud should be processed and a CAD model of the data should be obtained to obtain more useful information.

With the help of the GIS a variety of data sources and types can be integrated, visualized and used to make about resource management, and perform modeling and analysis. GIS helps organize bridge management information contained in various forms, such as inspection reports, rehab plans, and CAD files. Maintenance management and asset valuation may be enhanced with GIS and linear referencing systems

FINAL REPORT

FWHA/IN/JTRP-2003-13

MODERN TECHNOLOGIES FOR DESIGN DATA COLLECTION

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File No: 9-10-67
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and the
U.S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Indiana Department of Transportation or the Federal Highway Administration at the time of publication. The report does not constitute a standard, specification, or regulation.

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QuickBird Official Web Site (<http://www.digitalglobe.com/>)

Chapter 5

National Geodetic Survey (NGS): www.ngs.noaa.gov

Chapter 6

Center for Advanced Applications in Geographic Information Systems (CAAGIS)
website (<http://danpatch.ecn.purdue.edu/~caagis/ftp/gisdata/data.html>).

<http://www.infrasoft-civil.com>

<http://www.esri.com>

APPENDIX A

Lidar Movie

A flythrough movie which shows the data used and produced in the project which includes the DEM, satellite images and Lidar point clouds in a 3D environment.

SEE CD IN BACK COVER OF REPORT

APPENDIX B

Gis Data Movie

A more detailed flythrough movie which shows the data used and produced in the project which includes the DEM, satellite images and Lidar point clouds of the Bridgeport bridge in a 3D environment.

SEE CD IN BACK COVER OF REPORT

Datum = ANS84
Coordinate system = AMG
Projection = TMERC
Zone = Zone_16 : 90W to 84W
Linear unit = Meters

POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 4 COORDINATES rec1_4521_S2	N = 14401768.2228 E = 559870.5178	N 39°45'48.94867" W 86°18'03.66945" h 56.9641 H ** _ _	X = 316740.6527 Y = -4899372.0271 Z = 4057893.9231
	Az = 230°25'01.29906" O = 0°26'49.54672" t-T Con = +1.10390" Dist = 12807.9672 Scale= 0.999644128268	NSFA = 230°51'49.74188" NSBA = 50°47'23.16729" Ell Dist = 12812.6128 Delta h = +2.3767 Delta H = ** _ _ Gnd Dist= 12812.7296 Rad(A) = 6376795.8746 Skew Con = +0.00373" GsFA = 230°51'49.74215" Gsc Dist = 12812.6128 GsBA = 50°47'23.16756"	D X= -9584.2742 D Y= -5794.9187 D Z= -6223.0742 S D= 12812.7299
Pt# 6 COORDINATES rec3_1947_S1	N = 14393607.0537 E = 549999.3808	N 39°41'26.53345" W 86°25'00.75776" h 59.3408 H ** _ _	X = 307156.3785 Y = -4905166.9459 Z = 4051670.8490
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 8 COORDINATES rec1_4521_S3	N = 14401768.2295 E = 559870.5099	N 39°45'48.94889" W 86°18'03.66978" h 56.9954 H ** _ _	X = 316740.6462 Y = -4899372.0473 Z = 4057893.9484
	Az = 230°25'01.32176" O = 0°26'49.54651" t-T Con = +1.10390" Dist = 12807.9749 Scale= 0.999644128257	NSFA = 230°51'49.76437" NSBA = 50°47'23.18960" Ell Dist = 12812.6205 Delta h = +2.3668 Delta H = ** _ _ Gnd Dist= 12812.7374 Rad(A) = 6376795.8774 Skew Con = +0.00373" GsFA = 230°51'49.76463" Gsc Dist = 12812.6205 GsBA = 50°47'23.18986"	D X= -9584.2814 D Y= -5794.9140 D Z= -6223.0834 S D= 12812.7376
Pt# 7 COORDINATES rec3_1947_S2	N = 14393607.0566 E = 549999.3662	N 39°41'26.53354" W 86°25'00.75838" h 59.3622 H ** _ _	X = 307156.3648 Y = -4905166.9613 Z = 4051670.8650

POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 11 COORDINATES rec1_4521_S4	N = 14395177.4099 E = 563733.6875	N 39°42'14.17341" W 86°15'23.61218" h 49.7366 H ** _ _	X = 320818.4559 Y = -4903344.4376 Z = 4052795.2356
	Az = 249°18'09.20051" O = 0°28'29.78938" t-T Con = +0.37799" Dist = 7105.1096 Scale= 0.999650007519	NSFA = 249°46'38.61189" NSBA = 69°43'39.86391" Ell Dist = 7107.6327 Delta h = -5.6577 Delta H = ** _ _ Gnd Dist= 7107.6849 Rad(A) = 6383847.4740 Skew Con = +0.00184" GsFA = 249°46'38.61195" Gsc Dist = 7107.6327 GsBA = 69°43'39.86397"	D X= -6553.3204 D Y= -1994.2363 D Z= -1896.3728 S D= 7107.6871
Pt# 13 COORDINATES rec2_2656_S5	N = 14392666.2294 E = 557087.1429	N 39°40'54.41786" W 86°20'03.48627" h 44.0789 H ** _ _	X = 314265.1356 Y = -4905338.6740 Z = 4050898.8628
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 1 COORDINATES rec2_2656	N = 14393435.4620 E = 558418.9550	N 39°41'19.04343" W 86°19'07.33538" h 53.8441 H ** _ _	X = 315569.8336 Y = -4904776.4526 Z = 4051489.5770
	Az = 71°51'27.05131" O = 0°26'06.35274" t-T Con = -0.27388" Dist = 5592.6105 Scale= 0.999642015137	NSFA = 72°17'33.67793" NSBA = 252°19'56.56941" Ell Dist = 5594.5910 Delta h = -4.5153 Delta H = ** _ _ Gnd Dist= 5594.6363 Rad(A) = 6384527.5555 Skew Con = +0.00184" GsFA = 72°17'33.67796" Gsc Dist = 5594.5910 GsBA = 252°19'56.56944"	D X= +5248.4613 D Y= +1431.9901 D Z= +1305.0032 S D= 5594.6381
Pt# 2 COORDINATES rec1_4521	N = 14395176.8954 E = 563733.5295	N 39°42'14.15676" W 86°15'23.61900" h 49.3288 H ** _ _	X = 320818.2949 Y = -4903344.4625 Z = 4052794.5802
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 1 COORDINATES rec2_2656	N = 14393435.4620 E = 558418.9550	N 39°41'19.04343" W 86°19'07.33538" h 53.8441 H ** _ _	X = 315569.8336 Y = -4904776.4526 Z = 4051489.5770

	Az = 9°52'54.24423" O = 0°26'06.35274" t-T Con = -1.25605" Dist = 8458.2467 Scale= 0.999642015137	NSFA = 10°19'01.85302" NSBA = 190°19'42.54316" Ell Dist = 8461.2662 Delta h = +3.1199 Delta H = ** Gnd Dist= 8461.3396 Rad(A) = 6362307.1015 Skew Con = +0.00129" GsFA = 10°19'01.85306" Gsc Dist = 8461.2662 GsBA = 190°19'42.54321"	D X= +1170.8191 D Y= +5404.4255 D Z= +6404.3462 S D= 8461.3404
Pt# 4 COORDINATES rec1_4521_S2	N = 14401768.2228 E = 559870.5178	N 39°45'48.94867" W 86°18'03.66945" h 56.9641 H **	X = 316740.6527 Y = -4899372.0271 Z = 4057893.9231
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 1 COORDINATES rec2_2656	N = 14393435.4620 E = 558418.9550	N 39°41'19.04343" W 86°19'07.33538" h 53.8441 H **	X = 315569.8336 Y = -4904776.4526 Z = 4051489.5770
	Az = 150°30'41.44226" O = 0°26'06.35274" t-T Con = +0.00617" Dist = 47.7830 Scale= 0.999642015137	NSFA = 150°56'47.78883" NSBA = 330°56'48.41095" Ell Dist = 47.8001 Delta h = +0.0975 Delta H = ** Gnd Dist= 47.8005 Rad(A) = 6367465.1573 Skew Con = -0.00294" GsFA = 150°56'47.78883" Gsc Dist = 47.8001 GsBA = 330°56'48.41095"	D X= +24.8834 D Y= -25.2142 D Z= -32.0930 S D= 47.8006
Pt# 0 COORDINATES rec3_1947	N = 14393393.8690 E = 558442.4761	N 39°41'17.68858" W 86°19'06.36120" h 53.9417 H **	X = 315594.7170 Y = -4904801.6668 Z = 4051457.4840
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 1 COORDINATES rec2_2656	N = 14393435.4620 E = 558418.9550	N 39°41'19.04343" W 86°19'07.33538" h 53.8441 H **	X = 315569.8336 Y = -4904776.4526 Z = 4051489.5770
	Az = 271°10'03.11578" O = 0°26'06.35274" t-T Con = -0.02300" Dist = 8421.3225 Scale= 0.999642015137	NSFA = 271°36'09.49152" NSBA = 91°32'23.78568" Ell Dist = 8424.3863 Delta h = +5.4967 Delta H = **	D X= -8413.4551 D Y= -390.4933 D Z= +181.2720 S D= 8424.4627

		Gnd Dist= 8424.4610 Rad(A) = 6386864.8513 Skew Con = -0.00021" GsFA = 271°36'09.49151" Gsc Dist = 8424.3863 GsBA = 91°32'23.78568"	
Pt# 6 COORDINATES rec3_1947_S1	N = 14393607.0537 E = 549999.3808	N 39°41'26.53345" W 86°25'00.75776" h 59.3408 H ** _ _	X = 307156.3785 Y = -4905166.9459 Z = 4051670.8490
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 1 COORDINATES rec2_2656	N = 14393435.4620 E = 558418.9550	N 39°41'19.04343" W 86°19'07.33538" h 53.8441 H ** _ _	X = 315569.8336 Y = -4904776.4526 Z = 4051489.5770
	Az = 158°00'27.51596" O = 0°26'06.35274" t-T Con = +0.00798" Dist = 58.0613 Scale= 0.999642015137	NSFA = 158°26'33.86071" NSBA = 338°26'34.43267" Ell Dist = 58.0821 Delta h = +0.0218 Delta H = ** _ _ Gnd Dist= 58.0826 Rad(A) = 6364911.7160 Skew Con = -0.00237" GsFA = 158°26'33.86071" Gsc Dist = 58.0821 GsBA = 338°26'34.43267"	D X= +23.5134 D Y= -33.0729 D Z= -41.5559 S D= 58.0826
Pt# 3 COORDINATES rec4_2341_S1	N = 14393381.6256 E = 558440.6980	N 39°41'17.29190" W 86°19'06.43975" h 53.8659 H ** _ _	X = 315593.3470 Y = -4904809.5255 Z = 4051448.0211
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 1 COORDINATES rec2_2656	N = 14393435.4620 E = 558418.9550	N 39°41'19.04343" W 86°19'07.33538" h 53.8441 H ** _ _	X = 315569.8336 Y = -4904776.4526 Z = 4051489.5770
	Az = 204°34'53.67377" O = 0°26'06.35274" t-T Con = +1.10120" Dist = 8510.2876 Scale= 0.999642015137	NSFA = 205°00'58.92531" NSBA = 24°59'22.60435" Ell Dist = 8513.3558 Delta h = -29.1248 Delta H = ** _ _ Gnd Dist= 8513.4083 Rad(A) = 6366021.2104 Skew Con = +0.00122" GsFA = 205°00'58.92540" Gsc Dist = 8513.3558	D X= -3278.0801 D Y= -5120.9844 D Z= -5958.9160 S D= 8513.4582

Pt# 5 COORDINATES rec4_2341_S4	N = 14385696.4629 E = 554878.7732	GsBA = 24°59'22.60444" N 39°37'08.87386" W 86°21'38.27131" h 24.7194 H ** _ _	X = 312291.7535 Y = -4909897.4370 Z = 4045530.6610
POINT	MAPPING PROJECTION	GEODETTIC	EC CARTESIAN
Pt# 9 COORDINATES rec2_2656_S3	N = 14392666.2252 E = 557087.1444	N 39°40'54.41772" W 86°20'03.48620" h 44.0797 H ** _ _	X = 314265.1373 Y = -4905338.6772 Z = 4050898.8602
	Az = 17°00'12.48728" O = 0°25'30.27082" t-T Con = -1.36175" Dist = 9518.0673 Scale= 0.999640121339	NSFA = 17°25'44.11985" NSBA = 197°27'00.69173" Ell Dist = 9521.4741 Delta h = +12.9157 Delta H = ** _ _ Gnd Dist= 9521.5495 Rad(A) = 6363758.2830 Skew Con = +0.00209" GsFA = 17°25'44.11994" Gsc Dist = 9521.4741 GsBA = 197°27'00.69182"	D X= +2475.5088 D Y= +5966.6299 D Z= +6995.0882 S D= 9521.5584
Pt# 8 COORDINATES rec1_4521_S3	N = 14401768.2295 E = 559870.5099	N 39°45'48.94889" W 86°18'03.66978" h 56.9954 H ** _ _	X = 316740.6462 Y = -4899372.0473 Z = 4057893.9484
POINT	MAPPING PROJECTION	GEODETTIC	EC CARTESIAN
Pt# 9 COORDINATES rec2_2656_S3	N = 14392666.2252 E = 557087.1444	N 39°40'54.41772" W 86°20'03.48620" h 44.0797 H ** _ _	X = 314265.1373 Y = -4905338.6772 Z = 4050898.8602
	Az = 69°18'09.07244" O = 0°25'30.27082" t-T Con = -0.39212" Dist = 7105.1096 Scale= 0.999640121339	NSFA = 69°43'39.73538" NSBA = 249°46'38.48332" Ell Dist = 7107.6327 Delta h = +5.6569 Delta H = ** _ _ Gnd Dist= 7107.6849 Rad(A) = 6383823.0337 Skew Con = +0.00208" GsFA = 69°43'39.73544" Gsc Dist = 7107.6327 GsBA = 249°46'38.48337"	D X= +6553.3186 D Y= +1994.2395 D Z= +1896.3755 S D= 7107.6871
Pt# 11 COORDINATES rec1_4521_S4	N = 14395177.4099 E = 563733.6875	N 39°42'14.17341" W 86°15'23.61218" h 49.7366 H ** _ _	X = 320818.4559 Y = -4903344.4376 Z = 4052795.2356

POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 9 COORDINATES rec2_2656_S3	N = 14392666.2252 E = 557087.1444	N 39°40'54.41772" W 86°20'03.48620" h 44.0797 H ** _ _	X = 314265.1373 Y = -4905338.6772 Z = 4050898.8602
	Az = 277°33'40.45785" O = 0°25'30.27082" t-T Con = -0.12504" Dist = 7149.9485 Scale= 0.999640121339	NSFA = 277°59'10.85371" NSBA = 97°56'01.02045" Ell Dist = 7152.5564 Delta h = +15.2825 Delta H = ** _ _ Gnd Dist= 7152.6144 Rad(A) = 6386390.1627 Skew Con = -0.00105" GsFA = 277°59'10.85369" Gsc Dist = 7152.5564 GsBA = 97°56'01.02043"	D X= -7108.7726 D Y= +171.7159 D Z= +772.0048 S D= 7152.6306
Pt# 7 COORDINATES rec3_1947_S2	N = 14393607.0566 E = 549999.3662	N 39°41'26.53354" W 86°25'00.75838" h 59.3622 H ** _ _	X = 307156.3648 Y = -4905166.9613 Z = 4051670.8650
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 9 COORDINATES rec2_2656_S3	N = 14392666.2252 E = 557087.1444	N 39°40'54.41772" W 86°20'03.48620" h 44.0797 H ** _ _	X = 314265.1373 Y = -4905338.6772 Z = 4050898.8602
	Az = 178°57'48.83474" O = 0°25'30.27082" t-T Con = +0.00912" Dist = 62.9445 Scale= 0.999640121339	NSFA = 179°23'19.09645" NSBA = 359°23'19.11445" Ell Dist = 62.9672 Delta h = +0.1092 Delta H = ** _ _ Gnd Dist= 62.9676 Rad(A) = 6361491.2280 Skew Con = -0.00006" GsFA = 179°23'19.09645" Gsc Dist = 62.9672 GsBA = 359°23'19.11445"	D X= +3.2463 D Y= -40.1624 D Z= -48.3878 S D= 62.9677
Pt# 10 COORDINATES rec3_1947_S3	N = 14392603.2910 E = 557088.2830	N 39°40'52.37619" W 86°20'03.45801" h 44.1889 H ** _ _	X = 314268.3836 Y = -4905378.8396 Z = 4050850.4724
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 9 COORDINATES rec2_2656_S3	N = 14392666.2252 E = 557087.1444	N 39°40'54.41772" W 86°20'03.48620" h 44.0797 H ** _ _	X = 314265.1373 Y = -4905338.6772 Z = 4050898.8602

	Az = 197°34'50.93921" O = 0°25'30.27082" t-T Con = +0.98389" Dist = 7311.2578 Scale= 0.999640121339	NSFA = 198°00'20.22614" NSBA = 17°59'19.74280" Ell Dist = 7313.9007 Delta h = -19.3603 Delta H = ** Gnd Dist= 7313.9402 Rad(A) = 6363905.9877 Skew Con = +0.00094" GsFA = 198°00'20.22619" Gsc Dist = 7313.9007 GsBA = 17°59'19.74286"	D X= -1973.3838 D Y= -4558.7598 D Z= -5368.1992 S D= 7313.9659
Pt# 5 COORDINATES rec4_2341_S4	N = 14385696.4629 E = 554878.7732	N 39°37'08.87386" W 86°21'38.27131" h 24.7194 H **	X = 312291.7535 Y = -4909897.4370 Z = 4045530.6610
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 9 COORDINATES rec2_2656_S3	N = 14392666.2252 E = 557087.1444	N 39°40'54.41772" W 86°20'03.48620" h 44.0797 H **	X = 314265.1373 Y = -4905338.6772 Z = 4050898.8602
	Az = 184°53'33.76333" O = 0°25'30.27082" t-T Con = +0.01063" Dist = 73.5993 Scale= 0.999640121339	NSFA = 185°19'04.02352" NSBA = 5°19'03.84069" Ell Dist = 73.6258 Delta h = +0.0041 Delta H = ** Gnd Dist= 73.6263 Rad(A) = 6361705.6101 Skew Con = +0.00052" GsFA = 185°19'04.02352" Gsc Dist = 73.6258 GsBA = 5°19'03.84069"	D X= -3.8167 D Y= -47.1531 D Z= -56.4168 S D= 73.6263
Pt# 12 COORDINATES rec4_2341_S5	N = 14392592.8941 E = 557080.8671	N 39°40'52.04076" W 86°20'03.77254" h 44.0838 H **	X = 314261.3206 Y = -4905385.8302 Z = 4050842.4433
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 0 COORDINATES rec3_1947	N = 14393393.8690 E = 558442.4761	N 39°41'17.68858" W 86°19'06.36120" h 53.9417 H **	X = 315594.7170 Y = -4904801.6668 Z = 4051457.4840
	Az = 71°22'36.30634" O = 0°26'06.96252" t-T Con = -0.28046" Dist = 5583.4065 Scale= 0.999642048981	NSFA = 71°48'43.54931" NSBA = 251°51'05.81800" Ell Dist = 5585.3837 Delta h = -4.6129 Delta H = **	D X= +5223.5780 D Y= +1457.2043 D Z= +1337.0962 S D= 5585.4308

		Gnd Dist= 5585.4289 Rad(A) = 6384402.1289 Skew Con = +0.00188" GsFA = 71°48'43.54934" Gsc Dist = 5585.3837 GsBA = 251°51'05.81803"	
Pt# 2 COORDINATES rec1_4521	N = 14395176.8954 E = 563733.5295	N 39°42'14.15676" W 86°15'23.61900" h 49.3288 H ** _ _	X = 320818.2949 Y = -4903344.4625 Z = 4052794.5802
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 0 COORDINATES rec3_1947	N = 14393393.8690 E = 558442.4761	N 39°41'17.68858" W 86°19'06.36120" h 53.9417 H ** _ _	X = 315594.7170 Y = -4904801.6668 Z = 4051457.4840
	Az = 188°15'48.48223" O = 0°26'06.96252" t-T Con = +0.00182" Dist = 12.3719 Scale= 0.999642048981	NSFA = 188°41'55.44293" NSBA = 8°41'55.39276" Ell Dist = 12.3763 Delta h = -0.0758 Delta H = ** _ _ Gnd Dist= 12.3765 Rad(A) = 6362073.9282 Skew Con = +0.00104" GsFA = 188°41'55.44293" Gsc Dist = 12.3763 GsBA = 8°41'55.39276"	D X= -1.3700 D Y= -7.8587 D Z= -9.4629 S D= 12.3767
Pt# 3 COORDINATES rec4_2341_S1	N = 14393381.6256 E = 558440.6980	N 39°41'17.29190" W 86°19'06.43975" h 53.8659 H ** _ _	X = 315593.3470 Y = -4904809.5255 Z = 4051448.0211
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 10 COORDINATES rec3_1947_S3	N = 14392603.2910 E = 557088.2830	N 39°40'52.37619" W 86°20'03.45801" h 44.1889 H ** _ _	X = 314268.3836 Y = -4905378.8396 Z = 4050850.4724
	Az = 68°49'33.44831" O = 0°25'30.27057" t-T Con = -0.40195" Dist = 7126.5341 Scale= 0.999640122944	NSFA = 69°15'04.12082" NSBA = 249°18'02.84969" Ell Dist = 7129.0648 Delta h = +5.5477 Delta H = ** _ _ Gnd Dist= 7129.1173 Rad(A) = 6383683.7291 Skew Con = +0.00212" GsFA = 69°15'04.12088" Gsc Dist = 7129.0648	D X= +6550.0723 D Y= +2034.4019 D Z= +1944.7633 S D= 7129.1194

Pt# 11 COORDINATES rec1_4521_S4	N = 14395177.4099 E = 563733.6875	GsBA = 249°18'02.84975" N 39°42'14.17341" W 86°15'23.61218" h 49.7366 H ** _ _	X = 320818.4559 Y = -4903344.4376 Z = 4052795.2356
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 10 COORDINATES rec3_1947_S3	N = 14392603.2910 E = 557088.2830	N 39°40'52.37619" W 86°20'03.45801" h 44.1889 H ** _ _	X = 314268.3836 Y = -4905378.8396 Z = 4050850.4724
	Az = 358°57'43.91135" O = 0°25'30.27057" t-T Con = -0.00912" Dist = 62.9487 Scale= 0.999640122944	NSFA = 359°23'14.19104" NSBA = 179°23'14.17299" Ell Dist = 62.9714 Delta h = -0.1100 Delta H = ** _ _ Gnd Dist= 62.9718 Rad(A) = 6361490.6178 Skew Con = -0.00006" GsFA = 359°23'14.19104" Gsc Dist = 62.9714 GsBA = 179°23'14.17299"	D X= -3.2480 D Y= +40.1656 D Z= +48.3904 S D= 62.9719
Pt# 13 COORDINATES rec2_2656_S5	N = 14392666.2294 E = 557087.1429	N 39°40'54.41786" W 86°20'03.48627" h 44.0789 H ** _ _	X = 314265.1356 Y = -4905338.6740 Z = 4050898.8628
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 10 COORDINATES rec3_1947_S3	N = 14392603.2910 E = 557088.2830	N 39°40'52.37619" W 86°20'03.45801" h 44.1889 H ** _ _	X = 314268.3836 Y = -4905378.8396 Z = 4050850.4724
	Az = 215°29'57.38011" O = 0°25'30.27057" t-T Con = +0.00151" Dist = 12.7707 Scale= 0.999640122944	NSFA = 215°55'27.64918" NSBA = 35°55'27.44834" Ell Dist = 12.7753 Delta h = -0.1051 Delta H = ** _ _ Gnd Dist= 12.7754 Rad(A) = 6370206.5547 Skew Con = +0.00269" GsFA = 215°55'27.64918" Gsc Dist = 12.7753 GsBA = 35°55'27.44834"	D X= -7.0630 D Y= -6.9907 D Z= -8.0291 S D= 12.7758
Pt# 12 COORDINATES rec4_2341_S5	N = 14392592.8941 E = 557080.8671	N 39°40'52.04076" W 86°20'03.77254" h 44.0838 H ** _ _	X = 314261.3206 Y = -4905385.8302 Z = 4050842.4433

POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 5 COORDINATES rec4_2341_S4	N = 14385696.4629 E = 554878.7732	N 39°37'08.87386" W 86°21'38.27131" h 24.7194 H ** _ _	X = 312291.7535 Y = -4909897.4370 Z = 4045530.6610
	Az = 17°15'15.50723" O = 0°24'27.80579" t-T Con = -2.37449" Dist = 16829.1111 Scale= 0.999637077772	NSFA = 17°39'45.68751" NSBA = 197°42'02.74470" Ell Dist = 16835.1575 Delta h = +32.2447 Delta H = ** _ _ Gnd Dist= 16835.2653 Rad(A) = 6363753.0121 Skew Con = +0.00212" GsFA = 17°39'45.68778" Gsc Dist = 16835.1575 GsBA = 197°42'02.74497"	D X= +4448.8991 D Y= +10525.4099 D Z= +12363.2621 S D= 16835.2965
Pt# 4 COORDINATES rec1_4521_S2	N = 14401768.2228 E = 559870.5178	N 39°45'48.94867" W 86°18'03.66945" h 56.9641 H ** _ _	X = 316740.6527 Y = -4899372.0271 Z = 4057893.9231
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 5 COORDINATES rec4_2341_S4	N = 14385696.4629 E = 554878.7732	N 39°37'08.87386" W 86°21'38.27131" h 24.7194 H ** _ _	X = 312291.7535 Y = -4909897.4370 Z = 4045530.6610
	Az = 17°15'15.39117" O = 0°24'27.80579" t-T Con = -2.37449" Dist = 16829.1152 Scale= 0.999637077772	NSFA = 17°39'45.57145" NSBA = 197°42'02.62844" Ell Dist = 16835.1616 Delta h = +32.2760 Delta H = ** _ _ Gnd Dist= 16835.2695 Rad(A) = 6363753.0039 Skew Con = +0.00212" GsFA = 17°39'45.57172" Gsc Dist = 16835.1616 GsBA = 197°42'02.62871"	D X= +4448.8926 D Y= +10525.3897 D Z= +12363.2874 S D= 16835.3006
Pt# 8 COORDINATES rec1_4521_S3	N = 14401768.2295 E = 559870.5099	N 39°45'48.94889" W 86°18'03.66978" h 56.9954 H ** _ _	X = 316740.6462 Y = -4899372.0473 Z = 4057893.9484
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 5 COORDINATES rec4_2341_S4	N = 14385696.4629 E = 554878.7732	N 39°37'08.87386" W 86°21'38.27131" h 24.7194 H ** _ _	X = 312291.7535 Y = -4909897.4370 Z = 4045530.6610

	Az = 328°19'58.76251" O = 0°24'27.80579" t-T Con = -1.03661" Dist = 9294.4025 Scale= 0.999637077772	NSFA = 328°44'27.60491" NSBA = 148°42'18.38369" Ell Dist = 9297.8058 Delta h = +34.6214 Delta H = ** Gnd Dist= 9297.8670 Rad(A) = 6368249.5904 Skew Con = -0.00339" GsFA = 328°44'27.60478" Gsc Dist = 9297.8058 GsBA = 148°42'18.38356"	D X= -5135.3751 D Y= +4730.4911 D Z= +6140.1880 S D= 9297.9316
Pt# 6 COORDINATES rec3_1947_S1	N = 14393607.0537 E = 549999.3808	N 39°41'26.53345" W 86°25'00.75776" h 59.3408 H **	X = 307156.3785 Y = -4905166.9459 Z = 4051670.8490
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 5 COORDINATES rec4_2341_S4	N = 14385696.4629 E = 554878.7732	N 39°37'08.87386" W 86°21'38.27131" h 24.7194 H **	X = 312291.7535 Y = -4909897.4370 Z = 4045530.6610
	Az = 328°19'58.51928" O = 0°24'27.80579" t-T Con = -1.03661" Dist = 9294.4126 Scale= 0.999637077772	NSFA = 328°44'27.36168" NSBA = 148°42'18.14007" Ell Dist = 9297.8159 Delta h = +34.6428 Delta H = ** Gnd Dist= 9297.8772 Rad(A) = 6368249.6170 Skew Con = -0.00339" GsFA = 328°44'27.36155" Gsc Dist = 9297.8159 GsBA = 148°42'18.13994"	D X= -5135.3888 D Y= +4730.4757 D Z= +6140.2039 S D= 9297.9418
Pt# 7 COORDINATES rec3_1947_S2	N = 14393607.0566 E = 549999.3662	N 39°41'26.53354" W 86°25'00.75838" h 59.3622 H **	X = 307156.3648 Y = -4905166.9613 Z = 4051670.8650
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 12 COORDINATES rec4_2341_S5	N = 14392592.8941 E = 557080.8671	N 39°40'52.04076" W 86°20'03.77254" h 44.0838 H **	X = 314261.3206 Y = -4905385.8302 Z = 4050842.4433
	Az = 68°46'10.67531" O = 0°25'30.06672" t-T Con = -0.40355" Dist = 7137.2082 Scale= 0.999640112522	NSFA = 69°11'41.14558" NSBA = 249°14'40.07516" Ell Dist = 7139.7426 Delta h = +5.6528 Delta H = **	D X= +6557.1354 D Y= +2041.3926 D Z= +1952.7923 S D= 7139.7973

		Gnd Dist= 7139.7951 Rad(A) = 6383667.0607 Skew Con = +0.00212" GsFA = 69°11'41.14564" Gsc Dist = 7139.7426 GsBA = 249°14'40.07522"	
Pt# 11 COORDINATES rec1_4521_S4	N = 14395177.4099 E = 563733.6875	N 39°42'14.17341" W 86°15'23.61218" h 49.7366 H ** _ _	X = 320818.4559 Y = -4903344.4376 Z = 4052795.2356
POINT	MAPPING PROJECTION	GEODETIC	EC CARTESIAN
Pt# 12 COORDINATES rec4_2341_S5	N = 14392592.8941 E = 557080.8671	N 39°40'52.04076" W 86°20'03.77254" h 44.0838 H ** _ _	X = 314261.3206 Y = -4905385.8302 Z = 4050842.4433
	Az = 4°53'28.36658" O = 0°25'30.06672" t-T Con = -0.01063" Dist = 73.6033 Scale= 0.999640112522	NSFA = 5°18'58.44393" NSBA = 185°18'58.62672" Ell Dist = 73.6298 Delta h = -0.0049 Delta H = ** _ _ Gnd Dist= 73.6303 Rad(A) = 6361704.7625 Skew Con = +0.00052" GsFA = 5°18'58.44393" Gsc Dist = 73.6298 GsBA = 185°18'58.62672"	D X= +3.8150 D Y= +47.1563 D Z= +56.4195 S D= 73.6303
Pt# 13 COORDINATES rec2_2656_S5	N = 14392666.2294 E = 557087.1429	N 39°40'54.41786" W 86°20'03.48627" h 44.0789 H ** _ _	X = 314265.1356 Y = -4905338.6740 Z = 4050898.8628

Az - Grid Azimuth

NSFA - Normal Section Forward Azimuth

NSBA - Normal Section Back Azimuth

GsFA - Direct Geodetic Azimuth

t - Geometric azimuth

T - Azimuth Projected Geodetic

t-T Con - t-T Correction

Dist - Distance

Ell Dist - Ellipsoidal Distance

Gsc Dist - Geodetic Distance

S D - Slope Distance

Gnd Dist - Ground Distance

O - Convergence

Scale - Scale

Delta h - Delta h Ellipsoidal

Delta H - Delta H orthometric

Rad(A) - Radius of curvature of normal section

Skew Con - Inclination Correction

APPENDIX D

MOVE3 ANALYSIS TABLE

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*****
**                                     **
**               M O V E 3   Version 3.1.0               **
**                                     **
**               Design and Adjustment                    **
**               of                                         **
**               3D 2D and 1D Geodetic Networks           **
**                                     **
**               www.MOVE3.com                                           **
**               (c) 1993-2001 Grontmij Geogroep bv        **
**                                     **
** BridgeP                                           06-07-2003  21:21:12 **
*****
3D free network adjustment on User defined ellipsoid

PROJECT
R:\RA\CopyMove3\Bridge3\BridgeP.prj

STATIONS

Number of (partly) known stations      3
Number of unknown stations              4
Total                                  7

OBSERVATIONS

Directions                             24
Distances                             24
Zenith angles                          24
Azimuth angles                         0
Height differences                     0
GPS coordinate differences              0
GPS coordinates                        0
Geometrical relations                  0
Known coordinates                      7
GPS transformation parameters           0
Total                                  79

UNKNOWNNS

Coordinates                             21
Orientations                           4
Scale factors                          1
Vertical refraction coefficients        0
Azimuth offsets                        0
GPS transformation parameters           0
Deflections of the vertical             0
Additional transformation parameters     2
Total                                  28

Degrees of freedom                      51

ADJUSTMENT

Number of iterations                    1
Max coord correction in last iteration  0.0000 m

TESTING

Alfa (multi dimensional)                0.2642
Alfa 0 (one dimensional)                0.0010
Beta                                    0.80
Critical value W-test                    3.29

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Critical value T-test (3 dimensional) 4.24
Critical value T-test (2 dimensional) 5.91
Critical value F-test 1.12
F-test 0.023 accepted

VARIANCE COMPONENT ANALYSIS

	Variance	Redundancy
Terrestrial	0.023	51.0
Directions	0.076	15.0
Distances	0.000	18.0
Zenith angles	0.001	18.0

ELLIPSOID CONSTANTS

Ellipsoid	User defined
Semi major axis	6378137.0000 m
Inverse flattening	298.257222101

INPUT APPROXIMATE TERRESTRIAL COORDINATES

	Station	Latitude	Longitude	Height (m)	Id.Sd XY (m)	Id.Sd h (m)
0.0000	TS	39 41 19.97291	273 40 48.34319	201.5810	0.0000	
known	A	39 41 20.49997*	273 40 47.93480*	201.8801*	0.0000	0.0000
0.0000	B	39 41 21.07063	273 40 47.52009	201.9307	0.0000	
known	C	39 41 21.85450*	273 40 46.96060*	201.7783*	0.0000	0.0000
0.0000	D	39 41 21.52927	273 40 46.82512	201.6469	0.0000	
0.0000	E	39 41 20.82294	273 40 47.33666	201.9320	0.0000	
known	F	39 41 20.10279*	273 40 47.85620*	201.7890*	0.0000	0.0000

INPUT STANDARD DEVIATIONS OF KNOWN STATIONS

Station	Sd Latitude (m)	Sd Longitude (m)	Sd Height (m)	
A	0.0100*	0.0100*	0.0100*	base station
C	0.0100*	0.0100*	0.0100*	base station
F	0.0100	0.0100	0.0100*	base station

INPUT ADDITIONAL PARAMETERS

	Value	Sd
Scale factor	S0 1.0000000	free
Vertical refraction coefficient	Z0 0.13	fixed

INPUT OBSERVATIONS

	Station	Target	St ih	Tg ih	Reading
R0	A	F	1.4528	1.3716 m	359 58 14.0 dms desel
R0	A	B	1.4528	1.5417 m	141 58 49.0 dms desel
R1	A	F	1.4528	1.3716 m	178 58 40.0 dms desel
R1	A	B	1.4528	1.5417 m	321 58 07.0 dms desel
R0	TS	B	1.4040	1.3010 m	5 08 01.0 dms
S0					39.1292 m
Z0					89 38 20.0 dms
R0	TS	C	1.4040	1.5870 m	5 38 03.0 dms
S0					66.7376 m
Z0					89 40 34.0 dms
R0	TS	D	1.4040	1.3360 m	358 13 00.0 dms
S0					60.1078 m
Z0					90 00 08.0 dms

R3	TS	A	1.4040	1.2280 m	180 00 01.0 dms
S0					18.9386 m
Z0					89 37 32.0 dms
R3	TS	B	1.4040	1.3010 m	180 50 18.0 dms
S0					39.1294 m
Z0					89 38 13.0 dms
R3	TS	C	1.4040	1.5870 m	181 20 20.0 dms
S0					66.7376 m
Z0					89 40 34.0 dms
R2	TS	A	1.4040	1.2280 m	359 59 59.0 dms
S0					18.9386 m
Z0					270 22 11.0 dms
R1	TS	D	1.4040	1.3360 m	178 12 59.0 dms
S0					60.1080 m
Z0					269 59 42.0 dms
R1	TS	C	1.4040	1.5870 m	185 38 03.0 dms
S0					66.7374 m
Z0					270 19 02.0 dms
R1	TS	B	1.4040	1.3010 m	185 08 01.0 dms
S0					39.1296 m
Z0					270 21 24.0 dms
R2	TS	B	1.4040	1.3010 m	0 50 22.0 dms
S0					39.1296 m
Z0					270 21 41.0 dms
R2	TS	C	1.4040	1.5870 m	1 20 19.0 dms
S0					66.7376 m
Z0					270 19 15.0 dms
R2	TS	D	1.4040	1.3360 m	353 55 20.0 dms
S0					60.1078 m
Z0					269 59 36.0 dms
R2	TS	F	1.4040	1.5210 m	320 00 03.0 dms
S0					12.2830 m
Z0					271 31 34.0 dms
R3	TS	F	1.4040	1.5210 m	140 00 07.0 dms
S0					12.2830 m
Z0					88 28 09.0 dms
R1	TS	F	1.4040	1.5210 m	144 17 49.0 dms
S0					12.2830 m
Z0					271 31 26.0 dms
R0	TS	F	1.4040	1.5210 m	324 17 52.0 dms
S0					12.2832 m
Z0					88 28 18.0 dms
R3	TS	E	1.4040	1.1940 m	168 27 58.0 dms
S0					35.5342 m
Z0					89 46 22.0 dms
R2	TS	E	1.4040	1.1940 m	348 28 06.0 dms
S0					35.5342 m
Z0					270 13 25.0 dms
R1	TS	E	1.4040	1.1940 m	172 45 45.0 dms
S0					35.5340 m
Z0					270 13 33.0 dms
R0	TS	E	1.4040	1.1940 m	352 45 52.0 dms
S0					35.5342 m
Z0					89 46 23.0 dms
R3	TS	D	1.4040	1.3360 m	173 55 15.0 dms
S0					60.1080 m
Z0					90 00 06.0 dms
R1	TS	A	1.4040	1.2280 m	184 17 37.0 dms
S0					18.9386 m
Z0					270 22 22.0 dms
R0	TS	A	1.4040	1.2280 m	4 17 51.0 dms
S0					18.9384 m
Z0					89 37 24.0 dms

INPUT STANDARD DEVIATIONS OF OBSERVATIONS

Centring error	0.0010 m
Height of instrument error	0.0500 m

Station	Target	Sd abs	Sd rel	Sd tot
---------	--------	--------	--------	--------

105

S0			0.0100	0.0	0.0101 m	ppm
Z0			0 00 10.2	0 00 00.0	0 12 50.4 dms	dmskm
R0	TS	A	0 00 05.2	0 00 00.0	0 00 16.3 dms	dmskm
S0			0.0100	0.0	0.0101 m	ppm
Z0			0 00 10.2	0 00 00.0	0 12 50.4 dms	dmskm

COORDINATES (FREE NETWORK)

Station		Coordinate	Corr	Sd
TS	Latitude	39 41 19.97338	0.0146	0.0063 m
	Longitude	273 40 48.34317	-0.0004	0.0040 m
	Height	201.5784	-0.0026	0.0549 m
A	Latitude	39 41 20.49997*	0.0000	0.0000 m
	Longitude	273 40 47.93480*	0.0000	0.0000 m
	Height	201.8801*	0.0000	0.0000 m
B	Latitude	39 41 21.07080	0.0053	0.0054 m
	Longitude	273 40 47.52012	0.0007	0.0033 m
	Height	201.9325	0.0018	0.0433 m
C	Latitude	39 41 21.85450*	0.0000	0.0000 m
	Longitude	273 40 46.96060*	0.0000	0.0000 m
	Height	201.7783*	0.0000	0.0000 m
D	Latitude	39 41 21.52928	0.0004	0.0056 m
	Longitude	273 40 46.82524	0.0028	0.0048 m
	Height	201.6492	0.0023	0.0733 m
E	Latitude	39 41 20.82313	0.0057	0.0052 m
	Longitude	273 40 47.33673	0.0017	0.0040 m
	Height	201.9320	0.0000	0.0568 m
F	Latitude	39 41 20.10344*	0.0202	0.0061 m
	Longitude	273 40 47.85630*	0.0023	0.0056 m
	Height	201.7890*	0.0000	0.0000 m

EXTERNAL RELIABILITY

Station	Ext Rel	Station	Target
TS Latitude	-0.0143 m	TS	A
TS Longitude	0.0088 m	TS	A
TS Height	0.1260 m	TS	A
A Latitude	-0.0000 m	TS	A
A Longitude	0.0000 m	TS	A
A Height	0.0000 m	TS	A
B Latitude	0.0104 m	TS	B
B Longitude	-0.0060 m	TS	B
B Height	-0.0844 m	TS	B
C Latitude	0.0000 m	TS	A
C Longitude	-0.0000 m	TS	F
C Height	-0.0000 m	TS	A
D Latitude	0.0096 m	TS	D
D Longitude	-0.0073 m	TS	D
D Height	-0.0905 m	TS	A
E Latitude	0.0089 m	TS	E
E Longitude	-0.0081 m	TS	E
E Height	0.0848 m	TS	F
F Latitude	-0.0134 m	TS	A
F Longitude	-0.0114 m	TS	F
F Height	-0.0000 m	TS	A

ABSOLUTE STANDARD ELLIPSES AND CRITERION CIRCLES

C0 criterion	0.000 cm2
C1 criterion	1.000 cm2/km

Station	A	B	R	A/B	A/R	Phi	Sd Hgt
TS	0.0073	0.0011	0.0023 m	6.4	3.2	-35 deg	0.0549 m
A	0.0000	0.0000	0.0000 m	0.0	0.0	0 deg	0.0000 m
B	0.0062	0.0011	0.0015 m	5.8	4.1	-33 deg	0.0433 m
C	0.0000	0.0000	0.0000 m	0.0	0.0	0 deg	0.0000 m
D	0.0067	0.0030	0.0014 m	2.2	4.7	-43 deg	0.0733 m
E	0.0063	0.0018	0.0016 m	3.5	3.9	-40 deg	0.0568 m

F 0.0074 0.0038 0.0018 m 2.0 4.1 -45 deg 0.0000 m

ADJUSTED ADDITIONAL PARAMETERS

		Adj val	Corr	Sd
Scale factor	S0	0.9997389	-0.0002611	0.0001494

ADJUSTED OBSERVATIONS

	Station	Target	Adj obs	Resid	Sd
R0	TS	B	5 08 01.8	0 00 02.2	0 00 05.6 dms
S0			39.1294	-0.0003	0.0051 m
Z0			89 38 22.0	0 00 02.0	0 03 06.5 dms
R0	TS	C	5 38 02.5	0 00 00.9	0 00 04.7 dms
S0			66.7375	0.0001	0.0051 m
Z0			89 40 42.8	0 00 08.7	0 01 49.4 dms
R0	TS	D	358 12 59.8	0 00 01.2	0 00 04.8 dms
S0			60.1079	-0.0001	0.0051 m
Z0			90 00 14.0	0 00 06.0	0 02 01.5 dms
R3	TS	A	179 59 57.6	0 00 02.0	0 00 08.8 dms
S0			18.9385	0.0000	0.0051 m
Z0			89 37 35.7	0 00 03.7	0 06 25.2 dms
R3	TS	B	180 50 16.1	0 00 00.5	0 00 05.6 dms
S0			39.1294	-0.0001	0.0051 m
Z0			89 38 22.0	0 00 09.0	0 03 06.5 dms
R3	TS	C	181 20 16.9	0 00 01.7	0 00 04.7 dms
S0			66.7375	0.0001	0.0051 m
Z0			89 40 42.8	0 00 08.7	0 01 49.4 dms
R2	TS	A	0 00 00.4	0 00 02.8	0 00 08.8 dms
S0			18.9385	0.0000	0.0051 m
Z0			270 22 24.2	0 00 13.3	0 06 25.2 dms
R1	TS	D	178 12 57.6	0 00 00.0	0 00 04.8 dms
S0			60.1079	0.0001	0.0051 m
Z0			269 59 46.0	0 00 04.0	0 02 01.5 dms
R1	TS	C	185 38 00.4	0 00 01.3	0 00 04.7 dms
S0			66.7375	-0.0002	0.0051 m
Z0			270 19 17.3	0 00 15.2	0 01 49.4 dms
R1	TS	B	185 07 59.6	0 00 00.0	0 00 05.6 dms
S0			39.1294	0.0002	0.0051 m
Z0			270 21 38.0	0 00 14.0	0 03 06.5 dms
R2	TS	B	0 50 18.9	0 00 01.7	0 00 05.6 dms
S0			39.1294	0.0002	0.0051 m
Z0			270 21 38.0	0 00 03.0	0 03 06.5 dms
R2	TS	C	1 20 19.7	0 00 02.1	0 00 04.7 dms
S0			66.7375	0.0001	0.0051 m
Z0			270 19 17.3	0 00 02.3	0 01 49.4 dms
R2	TS	D	353 55 16.9	0 00 01.7	0 00 04.8 dms
S0			60.1079	-0.0001	0.0051 m
Z0			269 59 46.0	0 00 10.0	0 02 01.5 dms
R2	TS	F	320 00 06.2	0 00 04.6	0 00 12.6 dms
S0			12.2830	-0.0001	0.0051 m
Z0			271 31 38.2	0 00 04.3	0 09 53.9 dms
R3	TS	F	140 00 03.4	0 00 02.2	0 00 12.6 dms
S0			12.2830	-0.0001	0.0051 m
Z0			88 28 21.8	0 00 12.8	0 09 53.9 dms
R1	TS	F	144 17 46.9	0 00 00.8	0 00 12.6 dms
S0			12.2830	-0.0001	0.0051 m
Z0			271 31 38.2	0 00 12.2	0 09 53.9 dms
R0	TS	F	324 17 49.1	0 00 01.6	0 00 12.6 dms
S0			12.2830	0.0002	0.0051 m
Z0			88 28 21.8	0 00 03.8	0 09 53.9 dms
R3	TS	E	168 28 00.9	0 00 04.3	0 00 05.9 dms
S0			35.5341	0.0000	0.0051 m
Z0			89 46 26.8	0 00 04.7	0 03 25.3 dms
R2	TS	E	348 28 03.7	0 00 00.9	0 00 05.9 dms
S0			35.5341	0.0000	0.0051 m
Z0			270 13 33.3	0 00 08.2	0 03 25.3 dms
R1	TS	E	172 45 44.3	0 00 00.7	0 00 05.9 dms
S0			35.5341	-0.0001	0.0051 m

Z0			270 13 33.3	0 00 00.2	0 03 25.3	dms
R0	TS	E	352 45 46.5	0 00 04.1	0 00 05.9	dms
S0			35.5341	0.0000	0.0051	m
Z0			89 46 26.8	0 00 03.7	0 03 25.3	dms
R3	TS	D	173 55 14.1	0 00 00.5	0 00 04.8	dms
S0			60.1079	0.0001	0.0051	m
Z0			90 00 14.0	0 00 08.0	0 02 01.5	dms
R1	TS	A	184 17 41.1	0 00 05.5	0 00 08.8	dms
S0			18.9385	0.0000	0.0051	m
Z0			270 22 24.2	0 00 02.2	0 06 25.2	dms
R0	TS	A	4 17 43.2	0 00 06.3	0 00 08.8	dms
S0			18.9385	-0.0001	0.0051	m
Z0			89 37 35.7	0 00 11.7	0 06 25.2	dms

TEST OF OBSERVATIONS

	Station	Target	MDB	Red	BNR	W-test	T-test
R0	TS	B	0 00 47.7 dms	62	2.3	-0.30	
S0			0.0482 m	75	2.2	-0.03	
Z0			0 29 39.6 dms	75	2.2	-0.01	
R0	TS	C	0 00 39.1 dms	52	2.3	-0.19	
S0			0.0482 m	75	1.9	0.01	
Z0			0 17 24.2 dms	75	1.8	-0.05	
R0	TS	D	0 00 40.1 dms	54	1.9	-0.23	
S0			0.0482 m	75	2.0	-0.01	
Z0			0 19 19.1 dms	75	1.9	-0.03	
R3	TS	A	0 01 19.8 dms	71	2.4	0.15	
S0			0.0482 m	75	2.3	0.01	
Z0			1 01 15.9 dms	75	2.3	-0.01	
R3	TS	B	0 00 47.7 dms	62	2.3	0.07	
S0			0.0482 m	75	2.2	-0.01	
Z0			0 29 39.6 dms	75	2.2	-0.03	
R3	TS	C	0 00 39.1 dms	52	2.3	0.36	
S0			0.0482 m	75	1.9	0.01	
Z0			0 17 24.2 dms	75	1.8	-0.05	
R2	TS	A	0 01 19.8 dms	71	2.4	-0.21	
S0			0.0482 m	75	2.3	0.01	
Z0			1 01 15.9 dms	75	2.3	0.02	
R1	TS	D	0 00 40.1 dms	54	1.9	0.00	
S0			0.0482 m	75	2.0	0.01	
Z0			0 19 19.1 dms	75	1.9	0.02	
R1	TS	C	0 00 39.1 dms	52	2.3	0.26	
S0			0.0482 m	75	1.9	-0.02	
Z0			0 17 24.2 dms	75	1.8	0.08	
R1	TS	B	0 00 47.7 dms	62	2.3	0.00	
S0			0.0482 m	75	2.2	0.02	
Z0			0 29 39.6 dms	75	2.2	0.04	
R2	TS	B	0 00 47.7 dms	62	2.3	0.23	
S0			0.0482 m	75	2.2	0.02	
Z0			0 29 39.6 dms	75	2.2	-0.01	
R2	TS	C	0 00 39.1 dms	52	2.3	-0.42	
S0			0.0482 m	75	1.9	0.01	
Z0			0 17 24.2 dms	75	1.8	0.01	
R2	TS	D	0 00 40.1 dms	54	1.9	0.32	
S0			0.0482 m	75	2.0	-0.01	
Z0			0 19 19.1 dms	75	1.9	0.05	
R2	TS	F	0 01 57.5 dms	73	2.0	-0.22	
S0			0.0482 m	75	2.4	-0.01	
Z0			1 34 27.4 dms	75	2.2	0.00	
R3	TS	F	0 01 57.5 dms	73	2.0	0.11	
S0			0.0482 m	75	2.4	-0.01	
Z0			1 34 27.4 dms	75	2.2	-0.01	
R1	TS	F	0 01 57.5 dms	73	2.0	0.04	
S0			0.0482 m	75	2.4	-0.01	
Z0			1 34 27.4 dms	75	2.2	0.01	
R0	TS	F	0 01 57.5 dms	73	2.0	0.08	
S0			0.0482 m	75	2.4	0.02	
Z0			1 34 27.4 dms	75	2.2	-0.00	
R3	TS	E	0 00 50.4 dms	64	2.4	-0.55	
S0			0.0482 m	75	2.2	0.01	

Z0			0 32 39.6 dms	75	2.1	-0.01
R2	TS	E	0 00 50.4 dms	64	2.4	0.12
S0			0.0482 m	75	2.2	0.01
Z0			0 32 39.6 dms	75	2.1	0.02
R1	TS	E	0 00 50.4 dms	64	2.4	-0.10
S0			0.0482 m	75	2.2	-0.02
Z0			0 32 39.6 dms	75	2.1	0.00
R0	TS	E	0 00 50.4 dms	64	2.4	0.53
S0			0.0482 m	75	2.2	0.01
Z0			0 32 39.6 dms	75	2.1	-0.01
R3	TS	D	0 00 40.1 dms	54	1.9	-0.10
S0			0.0482 m	75	2.0	0.01
Z0			0 19 19.1 dms	75	1.9	-0.04
R1	TS	A	0 01 19.8 dms	71	2.4	-0.40
S0			0.0482 m	75	2.3	0.01
Z0			1 01 15.9 dms	75	2.3	0.00
R0	TS	A	0 01 19.8 dms	71	2.4	0.46
S0			0.0482 m	75	2.3	-0.02
Z0			1 01 15.9 dms	75	2.3	-0.02

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*****
**
**               M O V E 3   Version 3.1.0               **
**
**               Design and Adjustment                     **
**                  of                                     **
**               3D 2D and 1D Geodetic Networks           **
**
**               www.MOVE3.com                                           **
**               (c) 1993-2001 Grontmij Geogroep bv         **
**
** state_plane                                06-07-2003  21:20:29 **
*****

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3D connected network adjustment in TM projection

PROJECT

R:\RA\CopyMove3\Bridge3\state_plane.prj

STATIONS

Number of (partly) known stations	3
Number of unknown stations	4
Total	7

OBSERVATIONS

Directions	24
Distances	24
Zenith angles	24
Azimuth angles	0
Height differences	0
GPS coordinate differences	0
GPS coordinates	0
Geometrical relations	0
Known coordinates	9
GPS transformation parameters	0
Total	81

UNKNOWNNS

Coordinates	21
Orientations	4
Scale factors	1
Vertical refraction coefficients	0
Azimuth offsets	0

GPS transformation parameters	0
Deflections of the vertical	0
Additional transformation parameters	0
Total	26

Degrees of freedom	55
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ADJUSTMENT

Number of iterations	1
Max coord correction in last iteration	0.0000 m

TESTING

Alfa (multi dimensional)	0.2790
Alfa 0 (one dimensional)	0.0010
Beta	0.80
Critical value W-test	3.29
Critical value T-test (3 dimensional)	4.24
Critical value T-test (2 dimensional)	5.91
Critical value F-test	1.10
F-test	0.048 accepted

VARIANCE COMPONENT ANALYSIS

	Variance	Redundancy
Terrestrial	0.025	53.1
Directions	0.076	15.0
Distances	0.008	18.2
Zenith angles	0.002	19.9

PROJECTION AND ELLIPSOID CONSTANTS

Projection	TM
Longitude of origin/central meridian	272 55 00.00000
Latitude of origin	37 30 00.00000
Projection scale factor	1.000000000
False Easting	900000.0000 m
False Northing	250000.0000 m
Ellipsoid	User defined
Semi major axis	6378137.0000 m
Inverse flattening	298.257223563

INPUT APPROXIMATE TERRESTRIAL COORDINATES

	Station	X East (m)	Y North (m)	Height (m)	Id.Sd XY (m)	Id.Sd h (m)
known	A	965475.3293*	493269.5677*	201.8801*	0.0000	0.0000
known	F	965473.5608*	493257.3024*	201.7891*	0.0000	0.0000
0.0000	B	965465.2982	493287.0832	201.9307	0.0000	
0.0000	TS	965485.1986	493253.3956	201.5810	0.0000	
known	C	965451.7614*	493311.1451*	201.7783*	0.0000	0.0000
0.0000	D	965448.6186	493301.0872	201.6469	0.0000	
0.0000	E	965460.9926	493279.4072	201.9320	0.0000	

INPUT STANDARD DEVIATIONS OF KNOWN STATIONS

Station	Sd X East (m)	Sd Y North (m)	Sd Height (m)
A	0.0100	0.0100	0.0100
F	0.0100	0.0100	0.0100
C	0.0100	0.0100	0.0100

INPUT ADDITIONAL PARAMETERS

		Value	Sd	
Scale factor	S0	1.0000000		free
Vertical refraction coefficient	Z0	0.13		fixed

INPUT OBSERVATIONS

	Station	Target	St ih	Tg ih	Reading
R0	A	F	1.4528	1.3716 m	359 58 14.0 dms desel
R0	A	B	1.4528	1.5417 m	141 58 49.0 dms desel
R1	A	F	1.4528	1.3716 m	178 58 40.0 dms desel
R1	A	B	1.4528	1.5417 m	321 58 07.0 dms desel
R0	TS	B	1.4040	1.3010 m	5 08 01.0 dms
S0					39.1292 m
Z0					89 38 20.0 dms
R0	TS	C	1.4040	1.5870 m	5 38 03.0 dms
S0					66.7376 m
Z0					89 40 34.0 dms
R0	TS	D	1.4040	1.3360 m	358 13 00.0 dms
S0					60.1078 m
Z0					90 00 08.0 dms
R3	TS	A	1.4040	1.2280 m	180 00 01.0 dms
S0					18.9386 m
Z0					89 37 32.0 dms
R3	TS	B	1.4040	1.3010 m	180 50 18.0 dms
S0					39.1294 m
Z0					89 38 13.0 dms
R3	TS	C	1.4040	1.5870 m	181 20 20.0 dms
S0					66.7376 m
Z0					89 40 34.0 dms
R2	TS	A	1.4040	1.2280 m	359 59 59.0 dms
S0					18.9386 m
Z0					270 22 11.0 dms
R1	TS	D	1.4040	1.3360 m	178 12 59.0 dms
S0					60.1080 m
Z0					269 59 42.0 dms
R1	TS	C	1.4040	1.5870 m	185 38 03.0 dms
S0					66.7374 m
Z0					270 19 02.0 dms
R1	TS	B	1.4040	1.3010 m	185 08 01.0 dms
S0					39.1296 m
Z0					270 21 24.0 dms
R2	TS	B	1.4040	1.3010 m	0 50 22.0 dms
S0					39.1296 m
Z0					270 21 41.0 dms
R2	TS	C	1.4040	1.5870 m	1 20 19.0 dms
S0					66.7376 m
Z0					270 19 15.0 dms
R2	TS	D	1.4040	1.3360 m	353 55 20.0 dms
S0					60.1078 m
Z0					269 59 36.0 dms
R2	TS	F	1.4040	1.5210 m	320 00 03.0 dms
S0					12.2830 m
Z0					271 31 34.0 dms
R3	TS	F	1.4040	1.5210 m	140 00 07.0 dms
S0					12.2830 m
Z0					88 28 09.0 dms
R1	TS	F	1.4040	1.5210 m	144 17 49.0 dms
S0					12.2830 m
Z0					271 31 26.0 dms
R0	TS	F	1.4040	1.5210 m	324 17 52.0 dms
S0					12.2832 m
Z0					88 28 18.0 dms
R3	TS	E	1.4040	1.1940 m	168 27 58.0 dms
S0					35.5342 m
Z0					89 46 22.0 dms
R2	TS	E	1.4040	1.1940 m	348 28 06.0 dms

S0					35.5342 m
Z0					270 13 25.0 dms
R1	TS	E	1.4040	1.1940 m	172 45 45.0 dms
S0					35.5340 m
Z0					270 13 33.0 dms
R0	TS	E	1.4040	1.1940 m	352 45 52.0 dms
S0					35.5342 m
Z0					89 46 23.0 dms
R3	TS	D	1.4040	1.3360 m	173 55 15.0 dms
S0					60.1080 m
Z0					90 00 06.0 dms
R1	TS	A	1.4040	1.2280 m	184 17 37.0 dms
S0					18.9386 m
Z0					270 22 22.0 dms
R0	TS	A	1.4040	1.2280 m	4 17 51.0 dms
S0					18.9384 m
Z0					89 37 24.0 dms

INPUT STANDARD DEVIATIONS OF OBSERVATIONS

Centring error	0.0010 m
Height of instrument error	0.0500 m

	Station	Target	Sd abs	Sd rel	Sd tot		
R0	A	F	0 00 05.2	0 00 00.0	desel	dms	dmskm
R0	A	B	0 00 05.2	0 00 00.0	desel	dms	dmskm
R1	A	F	0 00 05.2	0 00 00.0	desel	dms	dmskm
R1	A	B	0 00 05.2	0 00 00.0	desel	dms	dmskm
R0	TS	B	0 00 05.2	0 00 00.0	0 00 09.1	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 06 12.9	dms	dmskm
R0	TS	C	0 00 05.2	0 00 00.0	0 00 06.8	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 03 38.8	dms	dmskm
R0	TS	D	0 00 05.2	0 00 00.0	0 00 07.1	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 04 02.9	dms	dmskm
R3	TS	A	0 00 05.2	0 00 00.0	0 00 16.3	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 12 50.2	dms	dmskm
R3	TS	B	0 00 05.2	0 00 00.0	0 00 09.1	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 06 12.9	dms	dmskm
R3	TS	C	0 00 05.2	0 00 00.0	0 00 06.8	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 03 38.8	dms	dmskm
R2	TS	A	0 00 05.2	0 00 00.0	0 00 16.3	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 12 50.2	dms	dmskm
R1	TS	D	0 00 05.2	0 00 00.0	0 00 07.1	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 04 02.9	dms	dmskm
R1	TS	C	0 00 05.2	0 00 00.0	0 00 06.8	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 03 38.8	dms	dmskm
R1	TS	B	0 00 05.2	0 00 00.0	0 00 09.1	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 06 12.9	dms	dmskm
R2	TS	B	0 00 05.2	0 00 00.0	0 00 09.1	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 06 12.9	dms	dmskm
R2	TS	C	0 00 05.2	0 00 00.0	0 00 06.8	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 03 38.8	dms	dmskm
R2	TS	D	0 00 05.2	0 00 00.0	0 00 07.1	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 04 02.9	dms	dmskm
R2	TS	F	0 00 05.2	0 00 00.0	0 00 24.3	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 19 47.6	dms	dmskm

R3	TS	F	0 00 05.2	0 00 00.0	0 00 24.3	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 19 47.6	dms	dmskm
R1	TS	F	0 00 05.2	0 00 00.0	0 00 24.3	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 19 47.6	dms	dmskm
R0	TS	F	0 00 05.2	0 00 00.0	0 00 24.3	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 19 47.6	dms	dmskm
R3	TS	E	0 00 05.2	0 00 00.0	0 00 09.7	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 06 50.6	dms	dmskm
R2	TS	E	0 00 05.2	0 00 00.0	0 00 09.7	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 06 50.6	dms	dmskm
R1	TS	E	0 00 05.2	0 00 00.0	0 00 09.7	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 06 50.6	dms	dmskm
R0	TS	E	0 00 05.2	0 00 00.0	0 00 09.7	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 06 50.6	dms	dmskm
R3	TS	D	0 00 05.2	0 00 00.0	0 00 07.1	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 04 02.9	dms	dmskm
R1	TS	A	0 00 05.2	0 00 00.0	0 00 16.3	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 12 50.2	dms	dmskm
R0	TS	A	0 00 05.2	0 00 00.0	0 00 16.3	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 12 50.2	dms	dmskm

COORDINATES (CONSTRAINED NETWORK)

Station	Coordinate	Corr	Sd
A X East	965475.3293*	0.0000	0.0000 m
Y North	493269.5678*	0.0001	0.0000 m
Height	201.8801*	0.0000	0.0000 m
F X East	965473.5608*	0.0000	0.0000 m
Y North	493257.3025*	0.0001	0.0000 m
Height	201.7891*	0.0000	0.0000 m
B X East	965465.3026	0.0044	0.0031 m
Y North	493287.0820	-0.0012	0.0050 m
Height	201.9369	0.0062	0.0408 m
TS X East	965485.2123	0.0137	0.0015 m
Y North	493253.3851	-0.0105	0.0010 m
Height	201.5875	0.0065	0.0203 m
C X East	965451.7614*	0.0000	0.0000 m
Y North	493311.1452*	0.0001	0.0000 m
Height	201.7783*	0.0000	0.0000 m
D X East	965448.6162	-0.0024	0.0042 m
Y North	493301.0886	0.0014	0.0054 m
Height	201.6517	0.0048	0.0408 m
E X East	965460.9955	0.0029	0.0039 m
Y North	493279.4021	-0.0051	0.0042 m
Height	201.9377	0.0057	0.0408 m

EXTERNAL RELIABILITY

Station	Ext Rel	Station	Target
A X East	0.0293 m	F X East	
Y North	0.0295 m	F Y North	
Height	0.1767 m	A Height	
F X East	0.0449 m	F X East	
Y North	0.0460 m	F Y North	
Height	0.1766 m	F Height	
B X East	0.1318 m	C X East	
Y North	0.1239 m	C Y North	
Height	-0.0844 m	TS	B
TS X East	-0.0681 m	C X East	

Y North	-0.0594 m		C Y North	
Height	0.0621 m		F Height	
C X East	0.2735 m		C X East	
Y North	0.2547 m		C Y North	
Height	0.1769 m		C Height	
D X East	0.2331 m		C X East	
Y North	0.2174 m		C Y North	
Height	-0.0844 m	Z0	TS	D
E X East	0.1054 m		C X East	
Y North	0.1003 m		C Y North	
Height	-0.0844 m	Z0	TS	E

ABSOLUTE STANDARD ELLIPSES

Station	A	B	A/B	Phi	Sd Hgt
A	0.0000	0.0000 m	0.0	-53 deg	0.0000 m
F	0.0000	0.0000 m	0.0	-44 deg	0.0000 m
B	0.0058	0.0011 m	5.4	-33 deg	0.0408 m
TS	0.0016	0.0008 m	2.1	-71 deg	0.0203 m
C	0.0000	0.0000 m	0.0	-86 deg	0.0000 m
D	0.0066	0.0014 m	4.7	-41 deg	0.0408 m
E	0.0057	0.0010 m	5.7	-47 deg	0.0408 m

ADJUSTED ADDITIONAL PARAMETERS

	Adj val	Corr	Sd
Scale factor	S0	1.0002476	0.0002476
			0.0000769

ADJUSTED OBSERVATIONS

	Station	Target	Adj obs	Resid	Sd
R0	TS	B	5 08 03.2	0 00 02.2	0 00 05.6 dms
S0			39.1294	-0.0003	0.0051 m
Z0			89 38 22.0	0 00 02.0	0 03 06.4 dms
R0	TS	C	5 38 03.9	0 00 00.9	0 00 04.7 dms
S0			66.7371	0.0005	0.0050 m
Z0			89 40 29.6	0 00 04.4	0 01 07.6 dms
R0	TS	D	358 13 01.2	0 00 01.2	0 00 04.8 dms
S0			60.1079	-0.0001	0.0051 m
Z0			90 00 14.0	0 00 06.0	0 02 01.4 dms
R3	TS	A	179 59 59.3	0 00 01.7	0 00 08.8 dms
S0			18.9404	-0.0018	0.0047 m
Z0			89 37 50.0	0 00 18.0	0 03 58.2 dms
R3	TS	B	180 50 17.5	0 00 00.5	0 00 05.6 dms
S0			39.1294	-0.0001	0.0051 m
Z0			89 38 22.0	0 00 09.0	0 03 06.4 dms
R3	TS	C	181 20 18.3	0 00 01.7	0 00 04.7 dms
S0			66.7371	0.0005	0.0050 m
Z0			89 40 29.6	0 00 04.4	0 01 07.6 dms
R2	TS	A	0 00 02.1	0 00 03.1	0 00 08.8 dms
S0			18.9404	-0.0018	0.0047 m
Z0			270 22 10.0	0 00 01.0	0 03 58.2 dms
R1	TS	D	178 12 59.0	0 00 00.0	0 00 04.8 dms
S0			60.1079	0.0001	0.0051 m
Z0			269 59 46.0	0 00 04.0	0 02 01.4 dms
R1	TS	C	185 38 01.7	0 00 01.3	0 00 04.7 dms
S0			66.7371	0.0003	0.0050 m
Z0			270 19 30.4	0 00 28.4	0 01 07.6 dms
R1	TS	B	185 08 01.0	0 00 00.0	0 00 05.6 dms
S0			39.1294	0.0002	0.0051 m
Z0			270 21 38.0	0 00 14.0	0 03 06.4 dms
R2	TS	B	0 50 20.3	0 00 01.7	0 00 05.6 dms
S0			39.1294	0.0002	0.0051 m
Z0			270 21 38.0	0 00 03.0	0 03 06.4 dms
R2	TS	C	1 20 21.1	0 00 02.1	0 00 04.7 dms
S0			66.7371	0.0005	0.0050 m
Z0			270 19 30.4	0 00 15.4	0 01 07.6 dms
R2	TS	D	353 55 18.3	0 00 01.7	0 00 04.8 dms

S0			60.1079	-0.0001	0.0051	m
Z0			269 59 46.0	0 00 10.0	0 02 01.4	dms
R2	TS	F	320 00 06.9	0 00 04.0	0 00 12.6	dms
S0			12.2828	0.0002	0.0048	m
Z0			271 30 47.7	0 00 46.3	0 06 07.3	dms
R3	TS	F	140 00 04.1	0 00 02.9	0 00 12.6	dms
S0			12.2828	0.0002	0.0048	m
Z0			88 29 12.3	0 01 03.3	0 06 07.3	dms
R1	TS	F	144 17 47.6	0 00 01.4	0 00 12.6	dms
S0			12.2828	0.0002	0.0048	m
Z0			271 30 47.7	0 00 38.3	0 06 07.3	dms
R0	TS	F	324 17 49.8	0 00 02.2	0 00 12.6	dms
S0			12.2828	0.0004	0.0048	m
Z0			88 29 12.3	0 00 54.3	0 06 07.3	dms
R3	TS	E	168 28 02.3	0 00 04.3	0 00 05.9	dms
S0			35.5341	0.0000	0.0051	m
Z0			89 46 26.8	0 00 04.7	0 03 25.3	dms
R2	TS	E	348 28 05.1	0 00 00.9	0 00 05.9	dms
S0			35.5341	0.0000	0.0051	m
Z0			270 13 33.3	0 00 08.2	0 03 25.3	dms
R1	TS	E	172 45 45.7	0 00 00.7	0 00 05.9	dms
S0			35.5341	-0.0001	0.0051	m
Z0			270 13 33.3	0 00 00.2	0 03 25.3	dms
R0	TS	E	352 45 47.9	0 00 04.1	0 00 05.9	dms
S0			35.5341	0.0000	0.0051	m
Z0			89 46 26.8	0 00 03.7	0 03 25.3	dms
R3	TS	D	173 55 15.5	0 00 00.5	0 00 04.8	dms
S0			60.1079	0.0001	0.0051	m
Z0			90 00 14.0	0 00 08.0	0 02 01.4	dms
R1	TS	A	184 17 42.8	0 00 05.8	0 00 08.8	dms
S0			18.9404	-0.0018	0.0047	m
Z0			270 22 10.0	0 00 12.0	0 03 58.2	dms
R0	TS	A	4 17 44.9	0 00 06.0	0 00 08.8	dms
S0			18.9404	-0.0020	0.0047	m
Z0			89 37 50.0	0 00 26.0	0 03 58.2	dms

TEST OF OBSERVATIONS

	Station	Target	MDB	Red	BNR	W-test	T-test
R0	TS	B	0 00 47.7 dms	62	2.4	-0.30	
S0			0.0482 m	75	2.2	-0.03	
Z0			0 29 39.3 dms	75	2.4	-0.01	
R0	TS	C	0 00 39.1 dms	52	2.4	-0.19	
S0			0.0481 m	75	1.8	0.06	
Z0			0 15 50.6 dms	90	1.3	0.02	
R0	TS	D	0 00 40.1 dms	54	2.4	-0.23	
S0			0.0482 m	75	2.0	-0.01	
Z0			0 19 18.9 dms	75	2.4	-0.03	
R3	TS	A	0 01 19.7 dms	71	2.4	0.12	
S0			0.0472 m	78	2.1	-0.20	
Z0			0 55 46.5 dms	90	1.3	-0.02	
R3	TS	B	0 00 47.7 dms	62	2.4	0.07	
S0			0.0482 m	75	2.2	-0.01	
Z0			0 29 39.3 dms	75	2.4	-0.03	
R3	TS	C	0 00 39.1 dms	52	2.4	0.36	
S0			0.0481 m	75	1.8	0.06	
Z0			0 15 50.6 dms	90	1.3	0.02	
R2	TS	A	0 01 19.7 dms	71	2.4	-0.23	
S0			0.0472 m	78	2.1	-0.20	
Z0			0 55 46.5 dms	90	1.3	-0.00	
R1	TS	D	0 00 40.1 dms	54	2.4	0.00	
S0			0.0482 m	75	2.0	0.01	
Z0			0 19 18.9 dms	75	2.4	0.02	
R1	TS	C	0 00 39.1 dms	52	2.4	0.26	
S0			0.0481 m	75	1.8	0.04	
Z0			0 15 50.6 dms	90	1.3	0.14	
R1	TS	B	0 00 47.7 dms	62	2.4	0.00	
S0			0.0482 m	75	2.2	0.02	
Z0			0 29 39.3 dms	75	2.4	0.04	
R2	TS	B	0 00 47.7 dms	62	2.4	0.23	

S0			0.0482 m	75	2.2	0.02
Z0			0 29 39.3 dms	75	2.4	-0.01
R2	TS	C	0 00 39.1 dms	52	2.4	-0.42
S0			0.0481 m	75	1.8	0.06
Z0			0 15 50.6 dms	90	1.3	0.07
R2	TS	D	0 00 40.1 dms	54	2.4	0.32
S0			0.0482 m	75	2.0	-0.01
Z0			0 19 18.9 dms	75	2.4	0.05
R2	TS	F	0 01 57.4 dms	73	2.4	-0.19
S0			0.0475 m	77	2.2	0.03
Z0			1 26 00.2 dms	90	1.3	-0.04
R3	TS	F	0 01 57.4 dms	73	2.4	0.14
S0			0.0475 m	77	2.2	0.03
Z0			1 26 00.2 dms	90	1.3	-0.06
R1	TS	F	0 01 57.4 dms	73	2.4	0.07
S0			0.0475 m	77	2.2	0.03
Z0			1 26 00.2 dms	90	1.3	-0.03
R0	TS	F	0 01 57.4 dms	73	2.4	0.11
S0			0.0475 m	77	2.2	0.05
Z0			1 26 00.2 dms	90	1.3	-0.05
R3	TS	E	0 00 50.4 dms	64	2.4	-0.55
S0			0.0482 m	75	2.2	0.01
Z0			0 32 39.1 dms	75	2.4	-0.01
R2	TS	E	0 00 50.4 dms	64	2.4	0.12
S0			0.0482 m	75	2.2	0.01
Z0			0 32 39.1 dms	75	2.4	0.02
R1	TS	E	0 00 50.4 dms	64	2.4	-0.10
S0			0.0482 m	75	2.2	-0.02
Z0			0 32 39.1 dms	75	2.4	0.00
R0	TS	E	0 00 50.4 dms	64	2.4	0.53
S0			0.0482 m	75	2.2	0.01
Z0			0 32 39.1 dms	75	2.4	-0.01
R3	TS	D	0 00 40.1 dms	54	2.4	-0.10
S0			0.0482 m	75	2.0	0.01
Z0			0 19 18.9 dms	75	2.4	-0.04
R1	TS	A	0 01 19.7 dms	71	2.4	-0.42
S0			0.0472 m	78	2.1	-0.20
Z0			0 55 46.5 dms	90	1.3	-0.02
R0	TS	A	0 01 19.7 dms	71	2.4	0.44
S0			0.0472 m	78	2.1	-0.22
Z0			0 55 46.5 dms	90	1.3	-0.04

[End of file]

Move3 with comments:

```

*****
**                                     **
**               M O V E 3   Version 3.1.0               **
**                                     **
**               Design and Adjustment                    **
**                      of                                **
**               3D 2D and 1D Geodetic Networks           **
**                                     **
**               www.MOVE3.com                             **
**               (c) 1993-2001 Grontmij Geogroep bv        **
**                                     **
** state_plane                                     22-07-2003 10:22:32 **
*****

```

3D connected network adjustment in TM projection

PROJECT

R:\RA\CopyMove3\Bridge3\state_plane.prj

STATIONS

Number of (partly) known stations	3
Number of unknown stations	4
Total	7

%%

COMMENTS

The seventh station is an arbitrary
location for the total station
and does not figure in the analysis
for Lidar data

%%

OBSERVATIONS

Directions	24
Distances	24
Zenith angles	24
Azimuth angles	0
Height differences	0
GPS coordinate differences	0
GPS coordinates	0
Geometrical relations	0
Known coordinates	9
GPS transformation parameters	0
Total	81

%%

COMMENTS

The Observations are the total number
of measurements performed during the
Survey and they include
Distances, Coordinates, Angles etc

%%

UNKNOWN

Coordinates	21
Orientations	4
Scale factors	1
Vertical refraction coefficients	0
Azimuth offsets	0
GPS transformation parameters	0
Deflections of the vertical	0
Additional transformation parameters	0
Total	26

```

Degrees of freedom                                     55

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
COMMENTS
The Unknowns refer to the variables that
the MOVE3 program will solve for.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

ADJUSTMENT

Number of iterations                                  1
Max coord correction in last iteration                0.0000 m

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
COMMENTS
The Adjustment parameters are set by
the user.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

TESTING

Alfa (multi dimensional)                             0.2790
Alfa 0 (one dimensional)                             0.0010
Beta                                                  0.80
Critical value W-test                                3.29
Critical value T-test (3 dimensional)                 4.24
Critical value T-test (2 dimensional)                 5.91
Critical value F-test                                1.10

F-test                                                0.048  accepted

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
COMMENTS
The F-test is a very commonly used
multi-dimensional test. The F-test is
often called the overall model test,
because it tests the model in general.
The F-value is tested against a critical
value of the F-distribution, which is
a function of the redundancy and the
significance level  $\alpha$ . The F-test can
be rejected either due to gross errors,
incorrect mathematical model or an
incorrect stochastic model. The
information provided by the F-test,
namely acceptance or
rejection of the null-hypothesis is not
very specific. Therefore if the test
is rejected, it is necessary to find
the cause of the rejection by tracing
errors in observations or assumptions.
A gross error in the observations will
then be revealed if a rejected F-Test
is followed up by a W-Test. In our
case, The F-test was accepted at 0.048
(The ratio  $s^2 / s^2$ ), against a critical
value set at 1.10 (default value in Move3).
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

VARIANCE COMPONENT ANALYSIS

Variance      Redundancy
Terrestrial    0.025      53.1

Directions     0.076      15.0
Distances      0.008      18.2
Zenith angles  0.002      19.9

```

PROJECTION AND ELLIPSOID CONSTANTS

```

Projection                TM
Longitude of origin/central meridian  272 55 00.00000
Latitude of origin        37 30 00.00000
Projection scale factor    1.000000000
False Easting              900000.0000 m
False Northing             250000.0000 m

Ellipsoid                  User defined
Semi major axis            6378137.0000 m
Inverse flattening         298.257223563
    
```

%%

COMMENTS

These are the parameters for the WGS84 ellipsoid that was used for the adjustment process and for using the state plane coordinate system for Indiana

%%

INPUT APPROXIMATE TERRESTRIAL COORDINATES

	Station	X East (m)	Y North (m)	Height (m)	Id.Sd XY (m)	Id.Sd h (m)
	A	965475.3293*	493269.5677*	201.8801*	0.0000	0.0000
known						
	F	965473.5608*	493257.3024*	201.7891*	0.0000	0.0000
known						
	B	965465.2982	493287.0832	201.9307	0.0000	0.0000
	TS	965485.1986	493253.3956	201.5810	0.0000	0.0000
	C	965451.7614*	493311.1451*	201.7783*	0.0000	0.0000
known						
	D	965448.6186	493301.0872	201.6469	0.0000	0.0000
	E	965460.9926	493279.4072	201.9320	0.0000	0.0000

%%

COMMENTS

These are input coordinates that the user needs to approximately assign as "Initial Approximation". If a particular station is a known point, they are specified and are distinguished by the * sign next to their names

%%

INPUT STANDARD DEVIATIONS OF KNOWN STATIONS

	Station	Sd X East (m)	Sd Y North (m)	Sd Height (m)
	A	0.0100	0.0100	0.0100
	F	0.0100	0.0100	0.0100
	C	0.0100	0.0100	0.0100

%%

COMMENTS

These are input standard deviations or errors that are associated with the known coordinates.

%%

INPUT ADDITIONAL PARAMETERS

		Value	Sd
Scale factor	S0	1.0000000	free
Vertical refraction coefficient	Z0	0.13	fixed

INPUT OBSERVATIONS

	Station	Target	St ih	Tg ih	Reading				
R0	A	F	1.4528	1.3716 m	359	58	14.0	dms	desel
R0	A	B	1.4528	1.5417 m	141	58	49.0	dms	desel
R1	A	F	1.4528	1.3716 m	178	58	40.0	dms	desel
R1	A	B	1.4528	1.5417 m	321	58	07.0	dms	desel
R0	TS	B	1.4040	1.3010 m	5	08	01.0	dms	
S0							39.1292	m	
Z0					89	38	20.0	dms	
R0	TS	C	1.4040	1.5870 m	5	38	03.0	dms	
S0							66.7376	m	
Z0					89	40	34.0	dms	
R0	TS	D	1.4040	1.3360 m	358	13	00.0	dms	
S0							60.1078	m	
Z0					90	00	08.0	dms	
R3	TS	A	1.4040	1.2280 m	180	00	01.0	dms	
S0							18.9386	m	
Z0					89	37	32.0	dms	
R3	TS	B	1.4040	1.3010 m	180	50	18.0	dms	
S0							39.1294	m	
Z0					89	38	13.0	dms	
R3	TS	C	1.4040	1.5870 m	181	20	20.0	dms	
S0							66.7376	m	
Z0					89	40	34.0	dms	
R2	TS	A	1.4040	1.2280 m	359	59	59.0	dms	
S0							18.9386	m	
Z0					270	22	11.0	dms	
R1	TS	D	1.4040	1.3360 m	178	12	59.0	dms	
S0							60.1080	m	
Z0					269	59	42.0	dms	
R1	TS	C	1.4040	1.5870 m	185	38	03.0	dms	
S0							66.7374	m	
Z0					270	19	02.0	dms	
R1	TS	B	1.4040	1.3010 m	185	08	01.0	dms	
S0							39.1296	m	
Z0					270	21	24.0	dms	
R2	TS	B	1.4040	1.3010 m	0	50	22.0	dms	
S0							39.1296	m	
Z0					270	21	41.0	dms	
R2	TS	C	1.4040	1.5870 m	1	20	19.0	dms	
S0							66.7376	m	
Z0					270	19	15.0	dms	
R2	TS	D	1.4040	1.3360 m	353	55	20.0	dms	
S0							60.1078	m	
Z0					269	59	36.0	dms	
R2	TS	F	1.4040	1.5210 m	320	00	03.0	dms	
S0							12.2830	m	
Z0					271	31	34.0	dms	
R3	TS	F	1.4040	1.5210 m	140	00	07.0	dms	
S0							12.2830	m	
Z0					88	28	09.0	dms	
R1	TS	F	1.4040	1.5210 m	144	17	49.0	dms	
S0							12.2830	m	
Z0					271	31	26.0	dms	
R0	TS	F	1.4040	1.5210 m	324	17	52.0	dms	
S0							12.2832	m	
Z0					88	28	18.0	dms	
R3	TS	E	1.4040	1.1940 m	168	27	58.0	dms	
S0							35.5342	m	
Z0					89	46	22.0	dms	
R2	TS	E	1.4040	1.1940 m	348	28	06.0	dms	
S0							35.5342	m	
Z0					270	13	25.0	dms	
R1	TS	E	1.4040	1.1940 m	172	45	45.0	dms	
S0							35.5340	m	
Z0					270	13	33.0	dms	
R0	TS	E	1.4040	1.1940 m	352	45	52.0	dms	
S0							35.5342	m	

Z0					89 46 23.0 dms
R3	TS	D	1.4040	1.3360 m	173 55 15.0 dms
S0					60.1080 m
Z0					90 00 06.0 dms
R1	TS	A	1.4040	1.2280 m	184 17 37.0 dms
S0					18.9386 m
Z0					270 22 22.0 dms
R0	TS	A	1.4040	1.2280 m	4 17 51.0 dms
S0					18.9384 m
Z0					89 37 24.0 dms

%%%
 COMMENTS
 These are Observations that were input
 into the program
 %%%

INPUT STANDARD DEVIATIONS OF OBSERVATIONS

Centring error 0.0010 m
 Height of instrument error 0.0500 m

	Station	Target	Sd abs	Sd rel	Sd tot		
R0	A	F	0 00 05.2	0 00 00.0	desel	dms	dmskm
R0	A	B	0 00 05.2	0 00 00.0	desel	dms	dmskm
R1	A	F	0 00 05.2	0 00 00.0	desel	dms	dmskm
R1	A	B	0 00 05.2	0 00 00.0	desel	dms	dmskm
R0	TS	B	0 00 05.2	0 00 00.0	0 00 09.1	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 06 12.9	dms	dmskm
R0	TS	C	0 00 05.2	0 00 00.0	0 00 06.8	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 03 38.8	dms	dmskm
R0	TS	D	0 00 05.2	0 00 00.0	0 00 07.1	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 04 02.9	dms	dmskm
R3	TS	A	0 00 05.2	0 00 00.0	0 00 16.3	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 12 50.2	dms	dmskm
R3	TS	B	0 00 05.2	0 00 00.0	0 00 09.1	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 06 12.9	dms	dmskm
R3	TS	C	0 00 05.2	0 00 00.0	0 00 06.8	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 03 38.8	dms	dmskm
R2	TS	A	0 00 05.2	0 00 00.0	0 00 16.3	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 12 50.2	dms	dmskm
R1	TS	D	0 00 05.2	0 00 00.0	0 00 07.1	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 04 02.9	dms	dmskm
R1	TS	C	0 00 05.2	0 00 00.0	0 00 06.8	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 03 38.8	dms	dmskm
R1	TS	B	0 00 05.2	0 00 00.0	0 00 09.1	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 06 12.9	dms	dmskm
R2	TS	B	0 00 05.2	0 00 00.0	0 00 09.1	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 06 12.9	dms	dmskm
R2	TS	C	0 00 05.2	0 00 00.0	0 00 06.8	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 03 38.8	dms	dmskm
R2	TS	D	0 00 05.2	0 00 00.0	0 00 07.1	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 04 02.9	dms	dmskm
R2	TS	F	0 00 05.2	0 00 00.0	0 00 24.3	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 19 47.6	dms	dmskm

R3	TS	F	0 00 05.2	0 00 00.0	0 00 24.3	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 19 47.6	dms	dmskm
R1	TS	F	0 00 05.2	0 00 00.0	0 00 24.3	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 19 47.6	dms	dmskm
R0	TS	F	0 00 05.2	0 00 00.0	0 00 24.3	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 19 47.6	dms	dmskm
R3	TS	E	0 00 05.2	0 00 00.0	0 00 09.7	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 06 50.6	dms	dmskm
R2	TS	E	0 00 05.2	0 00 00.0	0 00 09.7	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 06 50.6	dms	dmskm
R1	TS	E	0 00 05.2	0 00 00.0	0 00 09.7	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 06 50.6	dms	dmskm
R0	TS	E	0 00 05.2	0 00 00.0	0 00 09.7	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 06 50.6	dms	dmskm
R3	TS	D	0 00 05.2	0 00 00.0	0 00 07.1	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 04 02.9	dms	dmskm
R1	TS	A	0 00 05.2	0 00 00.0	0 00 16.3	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 12 50.2	dms	dmskm
R0	TS	A	0 00 05.2	0 00 00.0	0 00 16.3	dms	dmskm
S0			0.0100	0.0	0.0101	m	ppm
Z0			0 00 10.2	0 00 00.0	0 12 50.2	dms	dmskm

COORDINATES (CONSTRAINED NETWORK)

Station	Coordinate	Corr	Sd
A X East	965475.3293*	0.0000	0.0000 m
Y North	493269.5678*	0.0001	0.0000 m
Height	201.8801*	0.0000	0.0000 m
F X East	965473.5608*	0.0000	0.0000 m
Y North	493257.3025*	0.0001	0.0000 m
Height	201.7891*	0.0000	0.0000 m
B X East	965465.3026	0.0043	0.0031 m
Y North	493287.0820	-0.0013	0.0050 m
Height	201.9369	0.0062	0.0408 m
TS X East	965485.2123	0.0137	0.0015 m
Y North	493253.3851	-0.0105	0.0010 m
Height	201.5875	0.0065	0.0203 m
C X East	965451.7614*	0.0000	0.0000 m
Y North	493311.1452*	0.0001	0.0000 m
Height	201.7783*	0.0000	0.0000 m
D X East	965448.6162	-0.0024	0.0042 m
Y North	493301.0886	0.0014	0.0054 m
Height	201.6517	0.0047	0.0408 m
E X East	965460.9955	0.0030	0.0039 m
Y North	493279.4021	-0.0051	0.0042 m
Height	201.9377	0.0057	0.0408 m

%%

COMMENTS

These are the Adjusted Output
Coordinates of all the stations. We
used these coordinates to register the
Lidar data

%%

EXTERNAL RELIABILITY

Station	Ext Rel	Station	Target
A X East	0.0293 m	F X East	

Y North	0.0295 m		F Y North	
Height	0.1767 m		A Height	
F X East	0.0449 m		F X East	
Y North	0.0460 m		F Y North	
Height	0.1766 m		F Height	
B X East	0.1318 m		C X East	
Y North	0.1239 m		C Y North	
Height	-0.0844 m	Z0	TS	B
TS X East	-0.0681 m		C X East	
Y North	-0.0594 m		C Y North	
Height	0.0621 m		F Height	
C X East	0.2735 m		C X East	
Y North	0.2547 m		C Y North	
Height	0.1769 m		C Height	
D X East	0.2331 m		C X East	
Y North	0.2174 m		C Y North	
Height	-0.0844 m	Z0	TS	D
E X East	0.1054 m		C X East	
Y North	0.1003 m		C Y North	
Height	-0.0844 m	Z0	TS	E

ABSOLUTE STANDARD ELLIPSES

Station	A	B	A/B	Phi	Sd Hgt
A	0.0000	0.0000 m	0.0	-53 deg	0.0000 m
F	0.0000	0.0000 m	0.0	-44 deg	0.0000 m
B	0.0058	0.0011 m	5.4	-33 deg	0.0408 m
TS	0.0016	0.0008 m	2.1	-71 deg	0.0203 m
C	0.0000	0.0000 m	0.0	-86 deg	0.0000 m
D	0.0066	0.0014 m	4.7	-41 deg	0.0408 m
E	0.0057	0.0010 m	5.7	-47 deg	0.0408 m

ADJUSTED ADDITIONAL PARAMETERS

	Adj val	Corr	Sd
Scale factor	S0	1.0002476	0.0002476
			0.0000769

ADJUSTED OBSERVATIONS

Station	Target	Adj obs	Resid	Sd
R0	TS	B	5 08 03.2	0 00 02.2
S0			39.1294	-0.0003
Z0			89 38 22.0	0 00 02.0
R0	TS	C	5 38 03.9	0 00 00.9
S0			66.7371	0.0005
Z0			89 40 29.6	0 00 04.4
R0	TS	D	358 13 01.2	0 00 01.2
S0			60.1079	-0.0001
Z0			90 00 14.0	0 00 06.0
R3	TS	A	179 59 59.3	0 00 01.7
S0			18.9404	-0.0018
Z0			89 37 50.0	0 00 18.0
R3	TS	B	180 50 17.5	0 00 00.5
S0			39.1294	-0.0001
Z0			89 38 22.0	0 00 09.0
R3	TS	C	181 20 18.3	0 00 01.7
S0			66.7371	0.0005
Z0			89 40 29.6	0 00 04.4
R2	TS	A	0 00 02.1	0 00 03.1
S0			18.9404	-0.0018
Z0			270 22 10.0	0 00 01.0
R1	TS	D	178 12 59.0	0 00 00.0
S0			60.1079	0.0001
Z0			269 59 46.0	0 00 04.0
R1	TS	C	185 38 01.7	0 00 01.3
S0			66.7371	0.0003
Z0			270 19 30.4	0 00 28.4
R1	TS	B	185 08 01.0	0 00 00.0

S0			39.1294	0.0002	0.0051	m
Z0			270 21 38.0	0 00 14.0	0 03 06.4	dms
R2	TS	B	0 50 20.3	0 00 01.7	0 00 05.6	dms
S0			39.1294	0.0002	0.0051	m
Z0			270 21 38.0	0 00 03.0	0 03 06.4	dms
R2	TS	C	1 20 21.1	0 00 02.1	0 00 04.7	dms
S0			66.7371	0.0005	0.0050	m
Z0			270 19 30.4	0 00 15.4	0 01 07.6	dms
R2	TS	D	353 55 18.3	0 00 01.7	0 00 04.8	dms
S0			60.1079	-0.0001	0.0051	m
Z0			269 59 46.0	0 00 10.0	0 02 01.4	dms
R2	TS	F	320 00 06.9	0 00 04.0	0 00 12.6	dms
S0			12.2828	0.0002	0.0048	m
Z0			271 30 47.7	0 00 46.3	0 06 07.3	dms
R3	TS	F	140 00 04.1	0 00 02.9	0 00 12.6	dms
S0			12.2828	0.0002	0.0048	m
Z0			88 29 12.3	0 01 03.3	0 06 07.3	dms
R1	TS	F	144 17 47.6	0 00 01.4	0 00 12.6	dms
S0			12.2828	0.0002	0.0048	m
Z0			271 30 47.7	0 00 38.3	0 06 07.3	dms
R0	TS	F	324 17 49.8	0 00 02.2	0 00 12.6	dms
S0			12.2828	0.0004	0.0048	m
Z0			88 29 12.3	0 00 54.3	0 06 07.3	dms
R3	TS	E	168 28 02.3	0 00 04.3	0 00 05.9	dms
S0			35.5341	0.0000	0.0051	m
Z0			89 46 26.8	0 00 04.7	0 03 25.3	dms
R2	TS	E	348 28 05.1	0 00 00.9	0 00 05.9	dms
S0			35.5341	0.0000	0.0051	m
Z0			270 13 33.3	0 00 08.2	0 03 25.3	dms
R1	TS	E	172 45 45.7	0 00 00.7	0 00 05.9	dms
S0			35.5341	-0.0001	0.0051	m
Z0			270 13 33.3	0 00 00.2	0 03 25.3	dms
R0	TS	E	352 45 47.9	0 00 04.1	0 00 05.9	dms
S0			35.5341	0.0000	0.0051	m
Z0			89 46 26.8	0 00 03.7	0 03 25.3	dms
R3	TS	D	173 55 15.5	0 00 00.5	0 00 04.8	dms
S0			60.1079	0.0001	0.0051	m
Z0			90 00 14.0	0 00 08.0	0 02 01.4	dms
R1	TS	A	184 17 42.8	0 00 05.8	0 00 08.8	dms
S0			18.9404	-0.0018	0.0047	m
Z0			270 22 10.0	0 00 12.0	0 03 58.2	dms
R0	TS	A	4 17 44.9	0 00 06.0	0 00 08.8	dms
S0			18.9404	-0.0020	0.0047	m
Z0			89 37 50.0	0 00 26.0	0 03 58.2	dms

TEST OF OBSERVATIONS

	Station	Target	MDB	Red	BNR	W-test	T-test
R0	TS	B	0 00 47.7 dms	62	2.4	-0.30	
S0			0.0482 m	75	2.2	-0.03	
Z0			0 29 39.3 dms	75	2.4	-0.01	
R0	TS	C	0 00 39.1 dms	52	2.4	-0.19	
S0			0.0481 m	75	1.8	0.06	
Z0			0 15 50.6 dms	90	1.3	0.02	
R0	TS	D	0 00 40.1 dms	54	2.4	-0.23	
S0			0.0482 m	75	2.0	-0.01	
Z0			0 19 18.9 dms	75	2.4	-0.03	
R3	TS	A	0 01 19.7 dms	71	2.4	0.12	
S0			0.0472 m	78	2.1	-0.20	
Z0			0 55 46.5 dms	90	1.3	-0.02	
R3	TS	B	0 00 47.7 dms	62	2.4	0.07	
S0			0.0482 m	75	2.2	-0.01	
Z0			0 29 39.3 dms	75	2.4	-0.03	
R3	TS	C	0 00 39.1 dms	52	2.4	0.36	
S0			0.0481 m	75	1.8	0.06	
Z0			0 15 50.6 dms	90	1.3	0.02	
R2	TS	A	0 01 19.7 dms	71	2.4	-0.23	
S0			0.0472 m	78	2.1	-0.20	
Z0			0 55 46.5 dms	90	1.3	-0.00	
R1	TS	D	0 00 40.1 dms	54	2.4	0.00	

S0			0.0482 m	75	2.0	0.01
Z0			0 19 18.9 dms	75	2.4	0.02
R1	TS	C	0 00 39.1 dms	52	2.4	0.26
S0			0.0481 m	75	1.8	0.04
Z0			0 15 50.6 dms	90	1.3	0.14
R1	TS	B	0 00 47.7 dms	62	2.4	0.00
S0			0.0482 m	75	2.2	0.02
Z0			0 29 39.3 dms	75	2.4	0.04
R2	TS	B	0 00 47.7 dms	62	2.4	0.23
S0			0.0482 m	75	2.2	0.02
Z0			0 29 39.3 dms	75	2.4	-0.01
R2	TS	C	0 00 39.1 dms	52	2.4	-0.42
S0			0.0481 m	75	1.8	0.06
Z0			0 15 50.6 dms	90	1.3	0.07
R2	TS	D	0 00 40.1 dms	54	2.4	0.32
S0			0.0482 m	75	2.0	-0.01
Z0			0 19 18.9 dms	75	2.4	0.05
R2	TS	F	0 01 57.4 dms	73	2.4	-0.19
S0			0.0475 m	77	2.2	0.03
Z0			1 26 00.2 dms	90	1.3	-0.04
R3	TS	F	0 01 57.4 dms	73	2.4	0.14
S0			0.0475 m	77	2.2	0.03
Z0			1 26 00.2 dms	90	1.3	-0.06
R1	TS	F	0 01 57.4 dms	73	2.4	0.07
S0			0.0475 m	77	2.2	0.03
Z0			1 26 00.2 dms	90	1.3	-0.03
R0	TS	F	0 01 57.4 dms	73	2.4	0.11
S0			0.0475 m	77	2.2	0.05
Z0			1 26 00.2 dms	90	1.3	-0.05
R3	TS	E	0 00 50.4 dms	64	2.4	-0.55
S0			0.0482 m	75	2.2	0.01
Z0			0 32 39.1 dms	75	2.4	-0.01
R2	TS	E	0 00 50.4 dms	64	2.4	0.12
S0			0.0482 m	75	2.2	0.01
Z0			0 32 39.1 dms	75	2.4	0.02
R1	TS	E	0 00 50.4 dms	64	2.4	-0.10
S0			0.0482 m	75	2.2	-0.02
Z0			0 32 39.1 dms	75	2.4	0.00
R0	TS	E	0 00 50.4 dms	64	2.4	0.53
S0			0.0482 m	75	2.2	0.01
Z0			0 32 39.1 dms	75	2.4	-0.01
R3	TS	D	0 00 40.1 dms	54	2.4	-0.10
S0			0.0482 m	75	2.0	0.01
Z0			0 19 18.9 dms	75	2.4	-0.04
R1	TS	A	0 01 19.7 dms	71	2.4	-0.42
S0			0.0472 m	78	2.1	-0.20
Z0			0 55 46.5 dms	90	1.3	-0.02
R0	TS	A	0 01 19.7 dms	71	2.4	0.44
S0			0.0472 m	78	2.1	-0.22
Z0			0 55 46.5 dms	90	1.3	-0.04

[End of file]

APPENDIX E

Diagnostics of Registration within Cyclone

Mean Absolute Error:

for Enabled Constraints = 0.004 m

for Disabled Constraints = 0.000 m

Date: 2003.06.17 13:39:26

Database name : Bridgeport

ScanWorlds
ScanWorld 1
ScanWorld 2
ScanWorld 3
ScanWorld 4
ScanWorld 5
ScanWorld 6
ScanWorld 7
FINAL_c6pts

Constraints

Name	ScanWorld	ScanWorld	Type	On/Off	Weight	Error	Error Vector
TargetID: S8	ScanWorld 1	ScanWorld 2	Coincident: Sphere-Sphere	On	1.00	0.006 m	(0.004, -0.003, 0.004) m
TargetID: S4	ScanWorld 1	ScanWorld 2	Coincident: Sphere-Sphere	On	1.00	0.006 m	(0.001, -0.002, -0.005) m
TargetID: S5	ScanWorld 1	ScanWorld 2	Coincident: Sphere-Sphere	On	1.00	0.004 m	(-0.001, 0.004, 0.000) m
TargetID: S8	ScanWorld 1	ScanWorld 3	Coincident: Sphere-Sphere	On	1.00	0.005 m	(0.002, -0.001, 0.005) m
TargetID: S4	ScanWorld 1	ScanWorld 3	Coincident: Sphere-Sphere	On	1.00	0.001 m	(0.000, 0.000, -0.001) m
TargetID: S5	ScanWorld 1	ScanWorld 3	Coincident: Sphere-Sphere	On	1.00	0.005 m	(0.002, 0.001, -0.004) m
TargetID: S8	ScanWorld 1	ScanWorld 4	Coincident: Sphere-Sphere	On	1.00	0.007 m	(0.003, -0.005, 0.003) m
TargetID: S6	ScanWorld 1	ScanWorld 4	Coincident: Sphere-Sphere	On	1.00	0.002 m	(0.000, 0.001, -0.001) m
TargetID: S4	ScanWorld 1	ScanWorld 4	Coincident: Sphere-Sphere	On	1.00	0.005 m	(0.000, 0.001, -0.005) m
TargetID: S5	ScanWorld 1	ScanWorld 4	Coincident: Sphere-Sphere	On	1.00	0.003 m	(0.001, 0.003, -0.001) m
TargetID: S3	ScanWorld 1	ScanWorld 4	Coincident: Sphere-Sphere	On	1.00	0.004 m	(-0.003, -0.002, 0.001) m
TargetID: S2	ScanWorld 1	ScanWorld 4	Coincident: Sphere-Sphere	On	1.00	0.004 m	(-0.002, -0.001, 0.004) m
TargetID: S1	ScanWorld 1	ScanWorld 4	Coincident: Sphere-Sphere	On	1.00	0.002 m	(0.000, 0.000, 0.002) m
TargetID: S6	ScanWorld 1	ScanWorld 5	Coincident: Sphere-Sphere	On	1.00	0.001 m	(0.001, 0.000, -0.001) m
TargetID: S4	ScanWorld 1	ScanWorld 5	Coincident: Sphere-Sphere	On	1.00	0.005 m	(0.001, -0.001, -0.005) m
TargetID: S5	ScanWorld 1	ScanWorld 5	Coincident: Sphere-Sphere	On	1.00	0.002 m	(0.000, 0.002, -0.001) m
TargetID: S3	ScanWorld 1	ScanWorld 5	Coincident: Sphere-Sphere	On	1.00	0.003 m	(-0.002, 0.000, 0.002) m
TargetID: S2	ScanWorld 1	ScanWorld 5	Coincident: Sphere-Sphere	On	1.00	0.003 m	(-0.002, -0.001, 0.003) m
TargetID: S1	ScanWorld 1	ScanWorld 5	Coincident: Sphere-Sphere	On	1.00	0.002 m	(0.000, 0.001, 0.002) m
TargetID: S6	ScanWorld 1	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.002 m	(0.001, 0.002, -0.001) m
TargetID: S4	ScanWorld 1	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.005 m	(0.001, -0.002, -0.004) m
TargetID: S5	ScanWorld 1	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.003 m	(0.000, 0.002, -0.003) m
TargetID: S3	ScanWorld 1	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.004 m	(-0.001, 0.001, 0.004) m
TargetID: S7	ScanWorld 1	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.003 m	(-0.001, 0.002, -0.002) m
TargetID: S2	ScanWorld 1	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.004 m	(-0.003, -0.001, 0.003) m
TargetID: S1	ScanWorld 1	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.003 m	(0.002, -0.001, 0.002) m
TargetID: S7	ScanWorld 1	ScanWorld 7	Coincident: Sphere-Sphere	On	1.00	0.003 m	(0.001, 0.001, -0.002) m
TargetID: S2	ScanWorld 1	ScanWorld 7	Coincident: Sphere-Sphere	On	1.00	0.006 m	(-0.004, 0.000, 0.005) m
TargetID: S1	ScanWorld 1	ScanWorld 7	Coincident: Sphere-Sphere	On	1.00	0.002 m	(0.000, -0.002, 0.000) m
TargetID: S6	ScanWorld 1	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.010 m	(0.008, 0.004, -0.005) m
TargetID: S4	ScanWorld 1	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.004 m	(0.001, -0.003, 0.002) m

TargetID: S5	ScanWorld 1	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.007 m	(0.004, 0.005, -0.002) m
TargetID: S3	ScanWorld 1	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.012 m	(-0.006, 0.005, -0.009) m
TargetID: S2	ScanWorld 1	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.010 m	(-0.005, -0.005, 0.007) m
TargetID: S1	ScanWorld 1	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.006 m	(-0.004, -0.004, 0.002) m
TargetID: S8	ScanWorld 2	ScanWorld 3	Coincident: Sphere-Sphere	On	1.00	0.003 m	(-0.002, 0.001, 0.001) m
TargetID: S4	ScanWorld 2	ScanWorld 3	Coincident: Sphere-Sphere	On	1.00	0.004 m	(-0.001, 0.002, 0.004) m
TargetID: S5	ScanWorld 2	ScanWorld 3	Coincident: Sphere-Sphere	On	1.00	0.006 m	(0.003, -0.003, -0.004) m
TargetID: S8	ScanWorld 2	ScanWorld 4	Coincident: Sphere-Sphere	On	1.00	0.003 m	(0.000, -0.003, -0.002) m
TargetID: S4	ScanWorld 2	ScanWorld 4	Coincident: Sphere-Sphere	On	1.00	0.003 m	(-0.001, 0.003, 0.000) m
TargetID: S5	ScanWorld 2	ScanWorld 4	Coincident: Sphere-Sphere	On	1.00	0.002 m	(0.002, -0.001, -0.001) m
TargetID: S4	ScanWorld 2	ScanWorld 5	Coincident: Sphere-Sphere	On	1.00	0.001 m	(0.000, 0.001, 0.000) m
TargetID: S5	ScanWorld 2	ScanWorld 5	Coincident: Sphere-Sphere	On	1.00	0.003 m	(0.001, -0.002, -0.001) m
TargetID: S4	ScanWorld 2	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.001 m	(0.000, 0.000, 0.001) m
TargetID: S5	ScanWorld 2	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.003 m	(0.000, -0.002, -0.003) m
TargetID: S4	ScanWorld 2	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.007 m	(0.000, -0.001, 0.007) m
TargetID: S5	ScanWorld 2	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.005 m	(0.005, 0.001, -0.002) m
TargetID: S4	ScanWorld 3	ScanWorld 4	Coincident: Sphere-Sphere	On	1.00	0.004 m	(0.000, 0.001, -0.004) m
TargetID: S5	ScanWorld 3	ScanWorld 4	Coincident: Sphere-Sphere	On	1.00	0.004 m	(-0.001, 0.002, 0.003) m
TargetID: S8	ScanWorld 3	ScanWorld 4	Coincident: Sphere-Sphere	On	1.00	0.005 m	(0.002, -0.004, -0.002) m
TargetID: S4	ScanWorld 3	ScanWorld 5	Coincident: Sphere-Sphere	On	1.00	0.004 m	(0.001, -0.001, -0.004) m
TargetID: S5	ScanWorld 3	ScanWorld 5	Coincident: Sphere-Sphere	On	1.00	0.003 m	(-0.002, 0.001, 0.003) m
TargetID: S4	ScanWorld 3	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.004 m	(0.001, -0.002, -0.003) m
TargetID: S5	ScanWorld 3	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.003 m	(-0.002, 0.001, 0.001) m
TargetID: S4	ScanWorld 3	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.005 m	(0.001, -0.003, 0.003) m
TargetID: S5	ScanWorld 3	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.005 m	(0.002, 0.004, 0.002) m
TargetID: S6	ScanWorld 4	ScanWorld 5	Coincident: Sphere-Sphere	On	1.00	0.002 m	(0.001, -0.001, 0.000) m
TargetID: S5	ScanWorld 4	ScanWorld 5	Coincident: Sphere-Sphere	On	1.00	0.002 m	(-0.001, -0.001, 0.000) m
TargetID: S4	ScanWorld 4	ScanWorld 5	Coincident: Sphere-Sphere	On	1.00	0.002 m	(0.001, -0.001, 0.000) m
TargetID: S1	ScanWorld 4	ScanWorld 5	Coincident: Sphere-Sphere	On	1.00	0.001 m	(0.000, 0.001, 0.000) m
TargetID: S2	ScanWorld 4	ScanWorld 5	Coincident: Sphere-Sphere	On	1.00	0.001 m	(-0.001, 0.000, -0.001) m
TargetID: S3	ScanWorld 4	ScanWorld 5	Coincident: Sphere-Sphere	On	1.00	0.002 m	(0.001, 0.001, 0.001) m
TargetID: S6	ScanWorld 4	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.001 m	(0.001, 0.000, 0.000) m
TargetID: S5	ScanWorld 4	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.003 m	(-0.002, -0.001, -0.002) m
TargetID: S4	ScanWorld 4	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.003 m	(0.001, -0.002, 0.001) m
TargetID: S1	ScanWorld 4	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.002 m	(0.002, -0.001, 0.000) m
TargetID: S2	ScanWorld 4	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.002 m	(-0.001, 0.000, -0.001) m
TargetID: S3	ScanWorld 4	ScanWorld 6	Coincident: Sphere-Sphere	On	1.00	0.004 m	(0.002, 0.003, 0.002) m
TargetID: S1	ScanWorld 4	ScanWorld 7	Coincident: Sphere-Sphere	On	1.00	0.003 m	(0.000, -0.002, -0.002) m
TargetID: S2	ScanWorld 4	ScanWorld 7	Coincident: Sphere-Sphere	On	1.00	0.002 m	(-0.002, 0.001, 0.001) m
TargetID: S6	ScanWorld 4	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.010 m	(0.009, 0.003, -0.003) m
TargetID: S5	ScanWorld 4	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.004 m	(0.003, 0.002, -0.001) m
TargetID: S4	ScanWorld 4	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.008 m	(0.001, -0.004, 0.007) m
TargetID: S1	ScanWorld 4	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.005 m	(-0.004, -0.003, 0.000)

TargetID: S5	ScanWorld 6	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.006 m	(0.004, 0.003, 0.001) m
TargetID: S6	ScanWorld 6	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.009 m	(0.008, 0.002, -0.003) m
TargetID: S4	ScanWorld 6	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.007 m	(0.000, -0.001, 0.007) m
TargetID: S2	ScanWorld 6	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.007 m	(-0.002, -0.005, 0.004) m
TargetID: S3	ScanWorld 6	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.014 m	(-0.005, 0.004, -0.013) m
TargetID: S1	ScanWorld 6	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.006 m	(-0.005, -0.002, 0.000) m
TargetID: S2	ScanWorld 7	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.006 m	(-0.002, -0.005, 0.002) m
TargetID: S1	ScanWorld 7	FINAL_c6pts	Coincident: Sphere-Vertex	On	1.00	0.004 m	(-0.004, -0.001, 0.002) m

ScanWorld Transformations

ScanWorld 1

translation: (315552.607, -4904810.993, 4051405.876) m
rotation: (0.9769, -0.0685, -0.2026):143.449 deg

ScanWorld 2

translation: (315546.528, -4904805.987, 4051410.054) m
rotation: (0.8626, -0.1540, -0.4819):149.610 deg

ScanWorld 3

translation: (315578.441, -4904793.389, 4051422.946) m
rotation: (0.9650, -0.1250, -0.2304):159.092 deg

ScanWorld 4

translation: (315599.304, -4904800.214, 4051428.588) m
rotation: (0.9542, 0.0379, 0.2969):120.512 deg

ScanWorld 5

translation: (315560.783, -4904753.602, 4051487.429) m
rotation: (0.1255, -0.1932, -0.9731):166.481 deg

ScanWorld 6

translation: (315611.088, -4904733.609, 4051494.474) m
rotation: (0.2611, 0.3516, 0.8990):170.846 deg

ScanWorld 7

translation: (315588.525, -4904747.280, 4051477.079) m
rotation: (0.2911, 0.4396, 0.8497):175.487 deg

FINAL_c6pts

translation: (0.000, 0.000, 0.000) m
rotation: (0.0000, 1.0000, 0.0000):0.000 deg

Unused ControlSpace Objects : none

APPENDIX F

Presentation

Microsoft Office Powerpoint presentation for the project.

SEE CD IN BACK COVER OF REPORT