



---

# Forensic Mapping

---

Incident Documentation

Forensic Mapping Systems and Data Analysis Comparison

---

# Table of Contents

EXECUTIVE SUMMARY .....	3
<b>CHAPTER 1 - PURPOSE OF STUDY.....</b>	<b>4</b>
<b>BACKGROUND .....</b>	<b>4</b>
<b>SCOPE OF STUDY .....</b>	<b>4</b>
<b>DATA SOURCES.....</b>	<b>4</b>
<i>Sokkia Total Station Infrared.....</i>	<i>4</i>
<i>Sokkia Total Station Reflector-less .....</i>	<i>5</i>
<i>Sokkia Radian GPS .....</i>	<i>5</i>
<i>LTI Laser .....</i>	<i>5</i>
<b>CHAPTER 2 PROJECT METHODOLOGY .....</b>	<b>6</b>
<b>PREPARATION.....</b>	<b>6</b>
<b>SCENE SELECTION CRITERIA.....</b>	<b>9</b>
<b>DOCUMENTATION PROCEDURES.....</b>	<b>9</b>
<b>ANALYSIS OF CAPTURED DATA.....</b>	<b>10</b>
PROJECT TIME SPAN.....	10
<b>CHAPTER 3 - OPERATION OF SYSTEMS.....</b>	<b>10</b>
WHAT IS FORENSIC MAPPING? .....	10
EDM.....	11
HOW THE PHASE COMPARISON DISTANCE METHOD WORKS .....	11
<b><i>SOKKIA Total Station .....</i></b>	<b><i>13</i></b>
<i>Cost.....</i>	<i>13</i>
<i>Incident Severity.....</i>	<i>13</i>
<i>Manpower.....</i>	<i>13</i>
<i>Training.....</i>	<i>13</i>
<i>Proficiency.....</i>	<i>13</i>
<i>Maintenance.....</i>	<i>13</i>
GPS.....	13
<b><i>SOKKIA Radian.....</i></b>	<b><i>14</i></b>
<i>Cost.....</i>	<i>14</i>
<i>Incident Severity.....</i>	<i>14</i>
<i>Manpower.....</i>	<i>14</i>
<i>Training.....</i>	<i>14</i>
<i>Proficiency.....</i>	<i>14</i>
<i>Maintenance.....</i>	<i>14</i>
<b><i>LTI Laser Mapping.....</i></b>	<b><i>14</i></b>
<i>How a laser rangefinder works.....</i>	<i>14</i>
<b><i>Cost.....</i></b>	<b><i>15</i></b>
<b><i>Incident Severity.....</i></b>	<b><i>15</i></b>

<i>Manpower</i> .....	15
<i>Training</i> .....	16
<i>Proficiency</i> .....	16
<i>Maintenance</i> .....	16
<b>CHAPTER 4 - INFLUENCE ON SYSTEMS</b> .....	<b>16</b>
ENVIRONMENT.....	16
WEATHER .....	16
June 15 <sup>th</sup> 2000.....	17
Operating limitations.....	17
Impulse LR MapStar AE.....	17
Sokkia Set500.....	17
Sokkia 4110R .....	17
Sokkia Radian.....	18
Sokkia SDR33 .....	18
Operator .....	18
<b>CHAPTER 5 – DATA COMPARISON AND ACCURACY ANALYSIS</b> .....	<b>18</b>
TIME.....	18
LTI Radial with Azimuth.....	18
LTI Range Triangulation.....	19
Sokkia Set 500.....	19
Sokkia Radian GPS.....	19
Sokkia 4110R.....	21
Final Drawing.....	21
<b>CHAPTER 6 – GRAPHICAL ACCURACY ANALYSIS</b> .....	<b>28</b>
<b>CHAPTER 7 - TEST RESULTS</b> .....	<b>31</b>
Time .....	31
Accuracy.....	32
Data Comparison.....	36
Elevation.....	36
<b>CHAPTER 8 - FUTURE TRENDS</b> .....	<b>37</b>
TOTAL STATION.....	37
LASER.....	37
GPS.....	38
3D LASER SCAN.....	38
SOFTWARE.....	38
HUMAN .....	39
<b>CHAPTER 9 - CONCLUSIONS</b> .....	<b>40</b>
<b>CHAPTER 10 - RECOMMENDATIONS</b> .....	<b>40</b>
REFERENCES .....	41

## Incident Documentation

### Forensic Mapping Systems and Data Analysis

R.S. “Steve” McKinzie ACTAR 440

McKinzie & Associates L.L.C.

Jim Todd ACTAR 686

Ron Kurtz ACTAR 999

Doug Barlet P.E.

Sokkia Corporation

Jeff Young

Duke Dutch

Laser Technology Inc.

Sean Gavan

Mark Davis

### Executive Summary

This study is conducted to offer the reader a fair and accurate presentation on evidence documentation systems currently available. As outlined, these systems output are compared. The comparison covers areas such as, Average System Cost, Operating limitations, Environmental Considerations, Training and Maintenance. A side-by-side comparison performed at a controlled location where aerial documentation is available, is utilized for an additional comparison.

Each system with qualified operating personnel is studied at the control location as it is documented. Each system mapped specified points of equal number and complexity. The data points are then compared to one another.

This paper includes a complete list of data point geometry and graphic attributes. A data and graphic comparison is also provided.

## CHAPTER 1 - Purpose of Study

### Background

The introduction of electronic mapping into collision reconstruction on a large scale began nearly 10 years ago. First utilizing electronic levels, then total stations, lasers, and now GPS. Each system has different capabilities, operational requirements, and cost. New buyers have in some cases been left at the mercy of self-study when acquiring systems. This analysis is intended to examine the operational capabilities and accuracy of four forensic mapping systems.

### Scope of Study

The analysis team conducted a side-by-side comparison of an, infrared total station, laser total station, global positioning system, laser radial and range systems.

### Data Sources

Manufacturers were contacted and offered an opportunity to participate in these tests. Laser Technology, Nikon Corp., Sokkia Corp., and Topcon, were invited. The following equipment was provided for inclusion in the field test.

#### **Sokkia Total Station Infrared**

The new Sokkia SET500 combines the latest electronic technology and software enhancements in a rugged, lightweight design. Distance measurements through the miniaturized EDM<sup>1</sup> take less than 3 seconds and can measure more than a mile to a single prism. The SET500 can also measure to reflective sheet targets when it is not convenient to use a prism.

Software enhancements include functions such as job management, feature code listing, offset observation, area calculation and a bull's-eye leveling indicator. Additionally, the internal data storage of 4000 points offers the flexibility to meet the needs of any application.

A 12-button keyboard included on the SET500 seems to shorten the learning curve. First, the user can simplify the operating procedures for their application by assigning frequently used functions to the soft keys. Second, the arrow-key rocker panel allows the user to quickly move around the display and make selections. Last, the SET500 includes several designated keys for the most common functions. Improved visibility on the new high-density graphic displays on both sides of the instrument make reading the screen easy, even in bright sunlight.

---

<sup>1</sup> EDM, Electronic Distance Measuring

### **Sokkia Total Station Reflector-less**

The [Sokkia 4110R](#) total station features reflector-less EDM technology. This feature allows high accuracy distance measurements without prisms in addition to reflector sheet targets or customary prisms. This instrument has 5" angle accuracy and incorporates a dual axis compensation.

### **Sokkia Radian GPS**

The [Radian](#) receiver uses state-of-the-art dual-frequency technology to provide centimeter-level accuracy in real-time surveys and millimeter-level in post-processed surveys. Usable as a rover or base station, the data structure is conveniently formatted for real time (RTK) and post-processing applications. Front panel operation, access to the memory card and LED status indicators enables greater flexibility and ease of use.

### **LTI Laser**

Laser Technology, maker of the [Impulse](#) laser, introduced us to the [MapStar Angle Encoder](#). More than just an electronic compass, the Mapstar CM brings a host of new advances to azimuth measurement.

Small, lightweight, and rugged, the MapStar is built to survive in any environment just like the Impulse. The physical layout and data format of the MapStar interface with all Impulse models. Or, the unit can operate independently when needed. Controller boards, intelligent processing algorithms, and auto-compensators for field temperature and pitch/roll, enable the Mapstar CM to achieve azimuth accuracy. Simple field procedures allow you to calibrate on site, effectively adapting to changing magnetic environments. MapStar is designed to work seamlessly with data collectors, GPS equipment, and other mapping hardware/software solutions. Accessories such as GPS antenna mounts, cable management, and carry packs are available for Mapstar.

The Impulse laser is used alone to facilitate range triangulation measurements.

## CHAPTER 2 Project Methodology

### Preparation

The forensic map site is located in Olathe, Johnson County, Kansas USA (N.38° 51.385', W.094° 49.699'). While located within a municipality the location is considered an undeveloped business area located directly west of a new shopping mall. The intersection handles generally northbound and southbound traffic on Southpark Boulevard and generally eastbound and westbound traffic on Frontier Lane. The roadways do not run true North-South or East-West at the intersection.



Figure 1 NORTH ←<sup>2</sup>

Southpark Boulevard is a 4-lane asphalt roadway divided by a raised grass median with concrete curbing and drainage. North of the intersection, the roadway curves towards the northeast. While south of the intersection the roadway curves to due south.

---

<sup>2</sup> MJ Harden & Associates altitude 5000 msl

Frontier Lane is controlled both east and west of the intersection with stop signs. East of the intersection Frontier Lane is a 4-lane asphalt roadway divided by a raised grass median with concrete curbing and drainage. This section of the road curves toward the southeast. West of the intersection, Frontier Lane is a 2-lane asphalt roadway with concrete curbing and drainage. This leg of the intersection curves immediately towards the northwest then north.



Figure 2

Figure 3

The roadway surfaces were marked prior to mapping with green and blue paint dots approximately 1 inch in diameter, see figure 2. A total of 158 fixed points are selected to be mapped by each system that participated in the forensic mapping project. By specifying what fixed points to document, our goal was to assure each team documented the same number and location of points. These fixed points were along the joints between the concrete curbing and the asphalt roadway. See figure 3. Initially all pavement markings were marked for mapping. This raised the number of points to nearly 300. It was decided not to map the pavement marks for issues of time. Additionally, two control points were designated and mandated to be documented by each team.



Figure 4

These control points are located on the raised grass medians dividing Southpark and used to facilitate the graphic comparison of the multiple forensic maps.

### **Scene Selection Criteria**

The primary consideration for site selection is safety. The site has a relatively low speed, low traffic volume. Second, was the clear distinction between the asphalt pavement and the adjacent concrete curb edges. Third, the availability of a recent scale photograph, see figure 1.

### **Documentation Procedures**

The LTI, (Laser Technology Incorporated) team consisting of Sean Gavan of the LTI Denver, Colorado Office and Mark Davis with the Dayton, Ohio Police Department arrived at the scene on June 14, 2000 at approximately 07:15 AM.

The Sokkia team consisting of Jeff Young and Duke Dutch of Sokkia Corp. Olathe, Kansas Office arrived on June 15, 2000 at approximately 07:50 AM.

Each team participated in a site familiarization briefing. During this session, each team viewed the fixed points and control points previously discussed. The project management team did not dictate the measurement origin, first point or sequence of points to be recorded.

## Analysis of Captured Data

As each team selected different measurement origins, (occupied point, reference point, control point) a data point comparison is cumbersome in this presentation. The data is provided as a component of this report for review. The graphic analysis of a random selection of 16 points (approximately 10%) is utilized to compare the five systems measured fixed points in proximity to one another. Additionally, each forensic map is compared to the scale aerial photograph.

A select number of Polar measurements from the LTI radial angle encoder and the Sokkia theodolite are evaluated for accuracy. The Cartesian coordinates are calculated from the vertical and horizontal angle and electronic slope distance measurements. The LTI range triangulation data from this method of measuring does not facilitate a data measurement validation process.

Likewise the Sokkia Radian GPS system provided only latitude and longitude data. No method is available to validate the accuracy of the provided information.

## Project Time Span

Two days, June 14 and 15<sup>th</sup> 2000 were scheduled for the field project. LTI performed their mapping exercises on the 14<sup>th</sup>, while Sokkia used the 15<sup>th</sup>. Data evaluation occurred subsequent to the delivery of electronic data files. Approximately 40 man-hours were consumed evaluating data and maps.

## CHAPTER 3 - Operation of Systems

### What is Forensic Mapping?

Forensic mapping using a total station is a system used to document physical evidence at some critical incident, much like we have documented physical evidence at the scene of highway crashes for years. The system uses an absolute polar coordinate system of measuring in comparison to the base line coordinate or a triangulation system we normally use. Polar coordinate refers to fixing the location of evidence by an angle and radius. The system is comprised of four parts, a theodolite, EDM, Optical Prism, and data collector.

The theodolite measures angles on an azimuth measured traditionally from magnetic north. EDM stands for electronic distance measuring instrument. The EDM in most cases is a pulsed infrared diode. An optical prism is used to reflect the light emitted from the EDM. The Data collector captures the measurements made by the theodolite and EDM along with graphic attributes.

For each point of physical evidence measured, captured are the horizontal azimuth from north, and vertical angle from the Theodolite. In addition to that information, the distance from the total station is measured by the EDM. This geographical information is then combined with graphic attributes assigned to the point.

The accuracy of the system is dependent upon several things. First is the "rod man". His role is not only to recognize and assign the graphics to the position, but the placement of the prism over the item is important as the measurement is recorded from a known height above the position. Second is the theodolite. There are 360 degrees in one revolution, within each degree is 60 minutes and within each minute are 60 seconds. Ten seconds at 1000 feet is about .58". The density of air can affect the EDM. Barometric pressure and temperature affect air density. A 10° Celsius change equates to 10 parts per million change in a measurement. For the relatively short distances measured, this 10PPM difference is for the most part not measurable.

To ensure the system is measuring accurately, a reference measurement protocol should be utilized. The protocol calls for the first measurement at each site to be recorded to a mechanically measured distance. At the end of the site examination the same measurement is recorded a second time to ensure no changes in atmospheric conditions have affected the accuracy of distance measurements.

## EDM

### HOW THE PHASE COMPARISON DISTANCE METHOD WORKS

In this method, an infrared light emitting diode transmits a beam of light. This beam of light is traveling at the speed of light. By using an electronic circuit, this beam of light is modulated (or varied) at a controlled rate. This rate is called the frequency. Since the rate (or frequency) is controlled by the electronic circuit, it can be as slow as necessary to be used economically as a measuring reference.

When the light beam is modulated at a certain rate (or frequency) it is said to have a modulation wavelength. This is the distance the light beam travels during one complete cycle of the modulation.

The instrument's electronic circuits normally can only measure one complete cycle of modulation. This causes a condition known as "rollover". This occurs if one-half of the wavelength of the frequency used is smaller than the distance to be measured. As the light beam travels to the reflecting prism and is returned to the EDM, it covers the distance twice (Once going out - once coming back). Since the maximum distance the EDM can detect is one complete wavelength, it must take into account the return distance. For this reason, the maximum distance measured and displayed will be one half of the wavelength. If the distance is greater, than one half wavelength, by the time the light beam gets back to the EDM, another pulse of modulation has started and the distance measured starts over from zero. This is the 'ROLLOVER' point. An example is the RED. MD-

IA modulation frequency of 75 kilohertz (75 thousand cycles per second). One half wavelength for this frequency is 2000 meters. These units would 'ROLLOVER' at 2000 meters and a 2500 meter distance will be displayed as 500 meters.

Most EDM units use two or three frequencies for better accuracy. For example, the RED-IA uses 75 kHz and 15 MHz. Half wavelengths are 2000 meters for 75 kHz and 10 meters for 15 MHz. This eliminates the need to measure the very, small 10 meter portion of a 2000 meter wavelength. So the distance measured is actually a combination of two measurements. For examples with a displayed distance of 1234.567 meters, the 75 kHz frequency determines a distance of 1234 meters. The 15 MHz frequency determines a distance of 4.567 meters. These two distances are combined by the RED-LA microprocessor. The overlapped number (4 meters) is used as a check to ensure both frequencies are accurate. (If for some reason they don't agree, a coincidence error occurs.

As the light beam returns to the EDM from the prism, it passes through the optical system and is focused on the receiving diode. The strength of the returned light is very weak (measurement would be in 10 to the minus 9 power or nanowatts). The receiving diode detects the weak light and passes it into a preamplifier where its strength is increased to a level that can be used by a normal type electronic circuit. The received light strength must be increased approximately 1000 times before it is strong enough to be used for distance measurement. This is done by the preamp and the amplifiers on the receiver board.

On the receiver board, after the signal is amplified, it is run into and combined with a **local signal** from the transmitter board. The two signals are electronically subtracted with the result being an "INTERMEDIATE FREQUENCY" (This is called an IF Signal). This IF Signal has a frequency of 15 kHz. This is a much lower frequency and since both transmitted frequencies are MMD into this one frequency, the remainder of the circuitry only has 15 kHz to process.

The IF Signal is shaped into a square wave and becomes the RX OUT signal (Receiver Output). The signal goes to the computer board where it is compared with the Reference signal. The Reference signal comes directly from the transmitter board where it is generated by the same circuit used to modulate the emitting diode. The REFERENCE signal represents the timing of the emitted signal. When the IF signal and the REFERENCE signal are compared, the difference represents the time lag of the received signal. The compare circuit electrically compares the two signals and converts the result into digital pulses. These pulses can then be counted by the microprocessor to determine the distance.

[Distance](#)

[Rollover](#)

## SOKKIA Total Station

### Cost

\*<sup>3</sup> \$8,000 to \$12,000 for 5 to 10” accuracy

### Incident Severity

Minor traffic crashes to Major disasters

### Manpower

Usually two. Speed can be increased with three.

### Training

Operation of equipment, 16 hours.

Basic Forensic mapping and equipment operation, 40 hours.

### Proficiency

After initial training, frequent use.

### Maintenance

Annual calibrations and certification recommended.

### GPS

For a general understanding of Global Positioning visit [Trimble](#) online tutorial.

Additional webs sites are linked below

[U.S. Department of Defense](#)

[GPS Market place](#)

[GPS World online](#)

[Garmin](#)



---

<sup>3</sup> \* These cost do not reflect any specific dealer offer.

[National Geodetic Survey](#)

**SOKKIA [Radian](#)**

Cost

\$300 hand held positioning

\$42,000. Mapping accuracy of 1 centimeter.

Incident Severity

Minor traffic crashes to Major disasters

(Any incident without overhead cover)

Manpower

One

Training

Basic mapping + eight hours equipment

Proficiency

Frequent use

Maintenance

Virtually none



**[LTI Laser Mapping](#)**

**How a laser rangefinder works.**

The word Laser actually stands for "Light Amplification by Stimulated Emission of Radiation." It is a form of electromagnetic radiation the same as radio and microwaves. The difference is that light has a much higher frequency than radio or microwaves. The light emitted by a laser is no different than any other source except that it has a unique method of generating light.

The type of laser used in LTI products is an infrared semiconductor laser diode. The generated light energy has a wavelength of approx. 900

nanometers, with a beam divergence of 3 milliradians, equal to a beam width of about 3 m (or ft) at 1000 m (ft). Target acquisition times range from 0.3 to 0.7 seconds. This laser is completely eye safe, meeting FDA Class 1 specifications. This means that you could stare directly into the laser for 3 hours without any harm to your eyesight. The radiated light power of LTI lasers is on the order of 50 microwatts, or in other terms, it outputs only one twentieth the light power of a typical TV remote control, and far less than a flashlight.

LTI laser products calculate distance by measuring the time of flight of very short pulses of infrared light. This method is different from the traditional surveying instrument method of measuring phase shifts by comparing the incoming wavelength with the phase of the reflected light. Any solid object will reflect back a certain percentage of the emitted light energy - it need only be small for our sensitive detector to pick it up. We measure the time it takes a laser pulse to travel to the target and back with a precision, crystal-controlled time base. Knowing the speed of light, we then calculate the distance traveled. To increase accuracy, the LTI laser measures as many as sixty pulses, utilizing a least squares method of determining the range. Sophisticated error trapping algorithms are in place to ensure a reliable reading.

With the ability to shoot great distances to a multitude of targets, LTI lasers will undoubtedly be able to solve your measurement needs. Find the specific product best suited to your task by exploring the [Laser Application](#) pages.

## Cost

\$9,000 with Radian accuracy

\$6,000 using triangulation

## Incident Severity

Minor traffic crashes to Major disasters

## Manpower

One, using triangulation

Two, using the Radial compass option



## **Training**

Eight to Sixteen hours

## **Proficiency**

Frequent

## **Maintenance**

Virtually None

## **CHAPTER 4 - Influence on Systems**

### **Environment**

Environmental and weather conditions were recorded and compared to the environmental operating limitations for each piece of equipment. The weather conditions on both days were well within the tolerances for all the equipment used.

On June 14, 2000, the day LTI (Laser Technologies, Inc.) completed the exercise, the weather exhibited multiple conditions. The conditions at start time, approximately 07:30 hours, were cloudy, overcast, with light rain and moderate wind. As the day progressed, the rain ended, giving way to partly sunny condition and the winds increased.

On June 15, 2000, the day Sokkia completed the exercise, there were no adverse weather conditions. It was a sunny day with mild winds. The temperature increased steadily as the day progressed.

### **Weather**

The links below describe the weather conditions for two ASOS<sup>4</sup> stations near the Mapping site.

[IXD Weather](#) [OJC Weather](#) [NCDC](#)

June 14<sup>th</sup> 2000

OJC

---

<sup>4</sup> Automated Surface Observation System

Time	Temp F	Dew Point F	Pressure	Wind MPH	Direction
653	64.9	64	28.6	4	230
753	66.9		28.63	7	250
835		63		11	240
853	70	61	28.63	15	260
953	73	59	28.64	11	250
1053	73.9	57.9	28.64	12	260
1153	75.9	55.9	28.65	14	250
1253	75	55.9	28.64	14	260

June 15<sup>th</sup> 2000

OJC

Time	Temp F	Dew Point F	Pressure	Wind MPH	Direction
653	64	87	28.65	6	210
753	69.1	78	28.64	6	180
853	73	71	28.63	9	190
953	77	64	28.6	10	180
1053	79	58	28.58	14	180
1153	82	53	28.56	10	190
1253	82.9	46	28.53	15	220

## Operating limitations

Each piece of equipment has environmental operating limitations. Listed below are the environmental parameters in which each set of equipment can function.

### Impulse LR MapStar AE

The unit's operating temperature range is -22 to 122 degrees Fahrenheit (-30 to +50 C). The Mapstar Angle Encoder is water resistant. The Impulse LR is waterproof to IP 67 and NEMA 6.

### Sokkia Set500

- Water and dust protected to IPX6
- Operating Temperature -4° F to +122° F (-20° C to +50° C)

### Sokkia 4110R

- Water resistance Protected against falling water drops as defined by Japanese Industrial Standard, Class IPX2 (JIS Publ. C0920-1982).
- Operating temperature -4 F to +122 F (-20 C to +50 C)

### **Sokkia Radian**

Radian Receiver –

- Water Resistance Wind-driven rain and dust RTCA/DO-160 Category S (Equivalent to IPX4)
- Operating Temperature -40° F to +131° F (-40° C to +55° C)  
Storage Temperature -40° F to +185° F (-40° C to +85° C)
- Humidity 5 to 95 percent N/C

**GPS Antenna –**

- Temperature -40° F to +158° F (-40° C to +70° C )

### **Sokkia SDR33**

- Wind-driven rain and dust
- 1.5m (5 ft) drop to concrete
- Operating temperature -4° F to + 122° F (-20° C to + 50° C)
- Humidity Operates at 95 percent N/C

### **Operator**

The operators for the LTI (Laser Technologies, Inc.) equipment were Sean Gavan, from LTI, and Mark Davis, from the City of Dayton, Ohio Police Department. The operators for the Sokkia equipment were Jeff Young, and Duke Dutch, from Sokkia, Olathe, Kansas.

## **CHAPTER 5 - Data Comparison and Accuracy Analysis**

### **Time**

The completion time for each mapping exercise was recorded. The time record includes the time to set up the instrument and the time to document the site. The familiarization briefing is not included in the time record. The total number of points is listed, and an average time per point is calculated from the site documentation time. The results for each exercise, listed by equipment type, are presented in a table form below.

#### **LTI Radial with Azimuth**

The first LTI map was done using the Radial with Azimuth method. The equipment used was an Impulse 200LR with the Mapstar Angle encoder module. Using this method, the Impulse and Angle Encoder are stationary. The operator shoots to the various targets to document points. During this exercise, a second

operator participated moving to the various points and positioning a prism above them for the instrument operator to sight on. The instrument was moved to facilitate documenting several points that were obstructed by trees and bushes.

<b>Time In</b>	<b>Set up</b>	<b>First Point</b>	<b>Last Point</b>	<b>Site Time</b>	<b>Time Out</b>	<b>Total Points</b>
7:50	14 min	8:04	9:37	1 hr 33 min	9:37	159

The average point per minute was 1.71. The total time for the exercise was one hour and forty-seven minutes.

### **LTI Range Triangulation**

The second map was completed using the range triangulation method. Again the Impulse 200LR was used. This method involves the setup of two reference points. The operator then moves with the instrument to each point to be documented. Once over the target, the operator shoots back to each reference point. This method requires one operator. Each reference point was moved once in order to document the entire scene.

<b>Time In</b>	<b>Set up</b>	<b>First Point</b>	<b>Last Point</b>	<b>Site Time</b>	<b>Time Out</b>	<b>Total Points</b>
9:45	21 min	10:06	12:40	2 hrs 34 min	12:40	159

The average point per minute was 1.03. The total time for the exercise was two hours fifty-five minutes.

### **Sokkia Set 500**

This method of mapping uses the total station as a reference point and documents the position of each target point by angle and distance from the total station. It requires two operators, one to operate the total station, and the other to move from point to point with the prism.

<b>Time In</b>	<b>Set up</b>	<b>First Point</b>	<b>Last Point</b>	<b>Scene Time</b>	<b>Time Out</b>	<b>Total Points</b>
08:28	10 min	08:38	09:52	1 hr 14 min	09:52	158

The average point per minute was 2.13. The total time for the exercise was one hour twenty-four minutes.

### **Sokkia Radian GPS**

This method of mapping uses satellite-based GPS technology to document the site. This equipment acquires satellites signals to determine the position of points. This equipment requires one operator. The operator carries the equipment in a backpack and moves from point to point documenting the positions.

<b>Time In</b>	<b>Set up</b>	<b>First Point</b>	<b>Last Point</b>	<b>Scene Time</b>	<b>Time Out</b>	<b>Total Points</b>
10:05	51 min*	10:56	11:32	36 min	11:32	157

The average point per minute was 4.36. The total time for the exercise was one hour twenty-seven minutes. \*The set up time includes time to resolve equipment problems. One map was started, but power to the equipment was interrupted when an automatic theft alarm on the vehicle became activated and interrupted the power supply. The operator, Duke Dutch, was not using his own equipment. He was using a set of equipment kept at the distributor for demonstration. Once he set the equipment to the tolerances he is accustomed, the exercise was completed. Fifty-one minutes does not accurately reflect the time required to set up the equipment.

**Sokkia 4110R**

This unit uses the same method as the Sokkia Set 500; only a prism is not needed. At close range, the operator can shoot directly to the target. Prism paper can also be used with this station. In this exercise, the unit was used with vertical target positioned on or over each target.

<b>Time In</b>	<b>Set up</b>	<b>First Point</b>	<b>Last Point</b>	<b>Scene Time</b>	<b>Time Out</b>	<b>Total Points</b>
11:47	5 min	11:52	13:00	1 hr 8 min	13:00	87

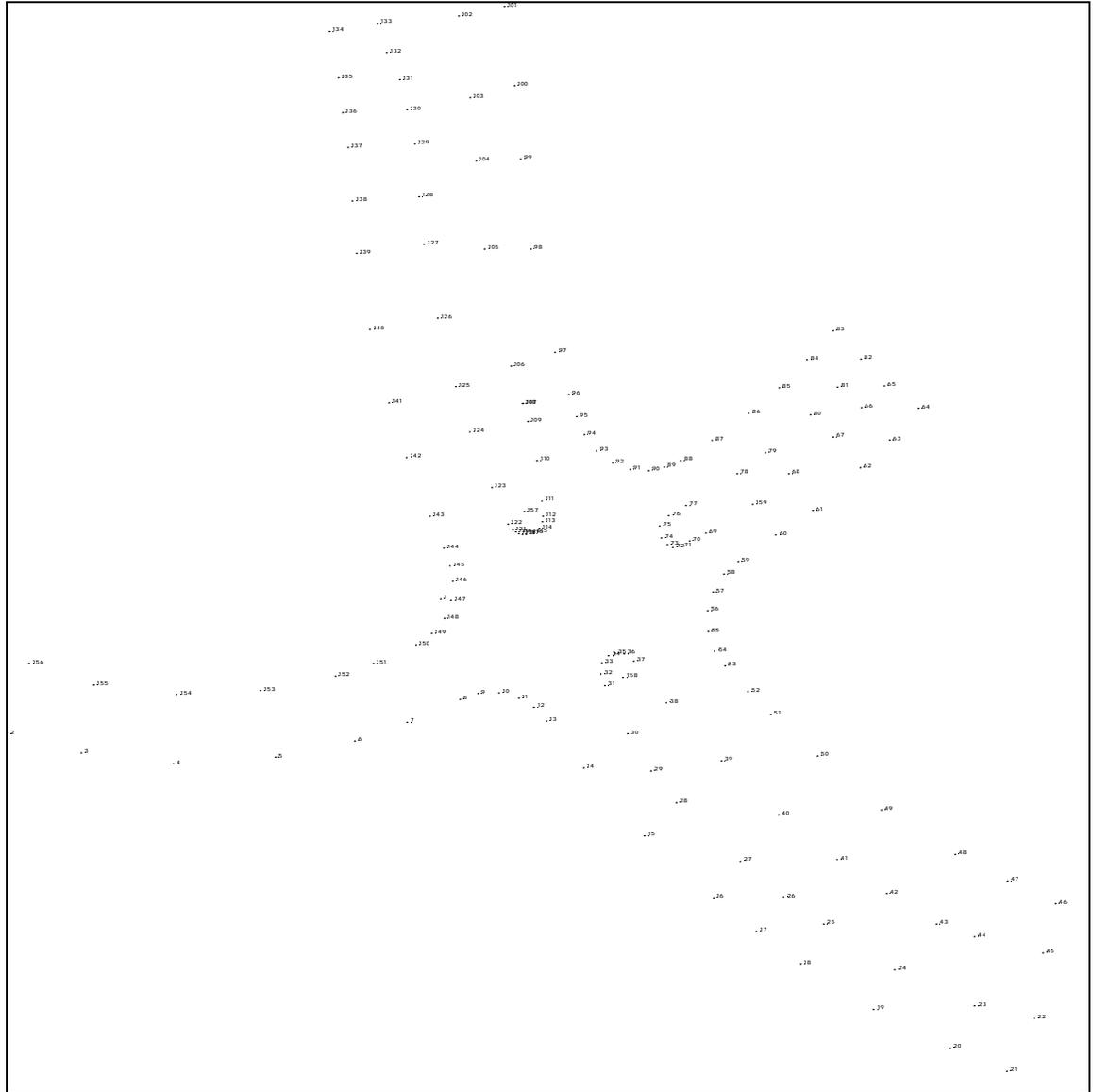
The set up time is greatly reduced in this exercise due to the tripod already being in place from the earlier exercise with the Set500. Due to the positions of marked points on the roadway relative to curb lines, bushes, and other obstacles, only 87 of the marked points were documented. The average time per point was 1.27. The total time for the exercise was one hour thirteen minutes. It is possible to utilize multiple station moves to capture all points

**Final Drawing**

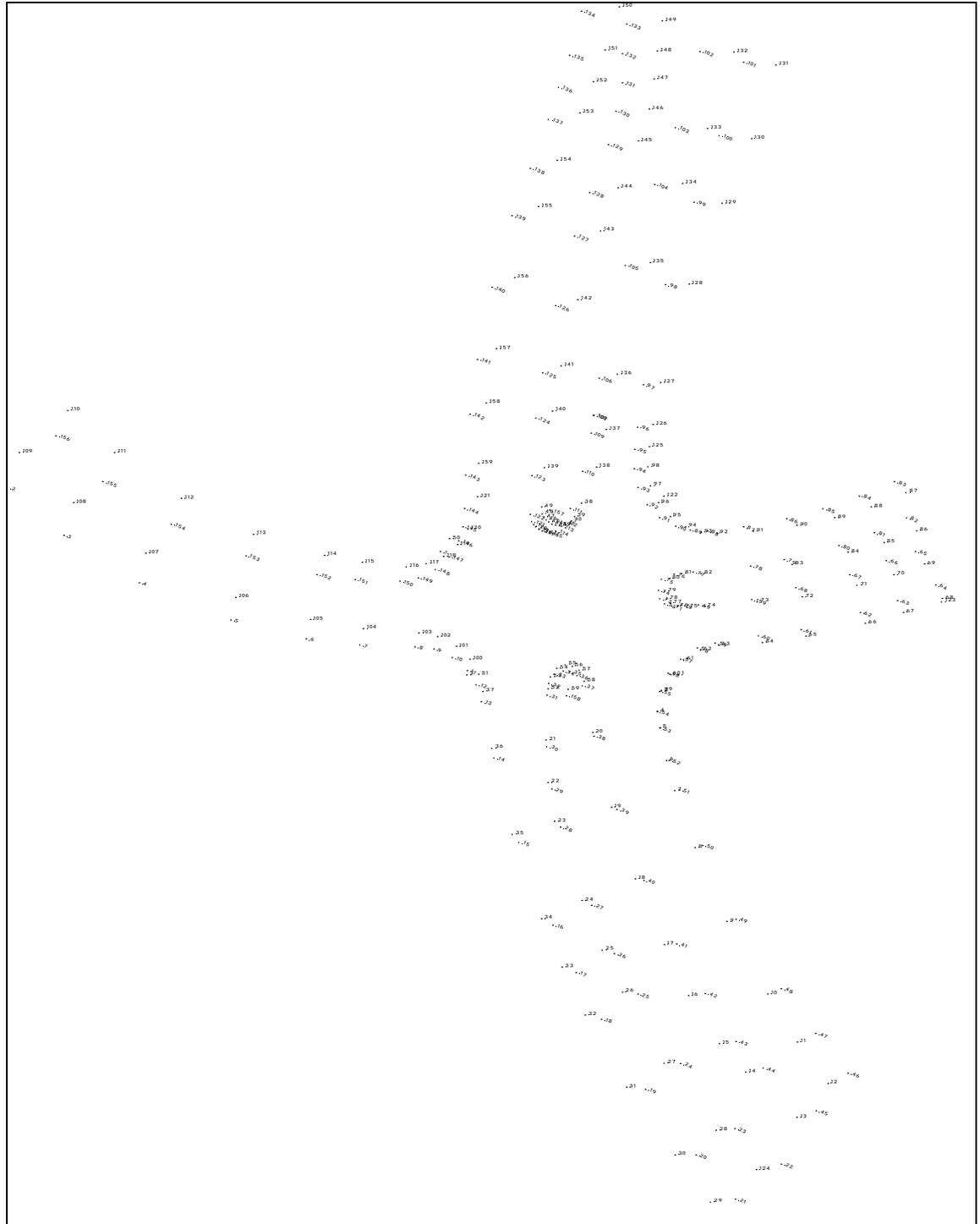
Five drawings follow and have been reproduced from the supplied DXF files into a WMF file for insertion into this report. The original DXF files can be found on the WREX CD

All photographic documentation during the field project is located on the WREX CD under Forensic Mapping Photos.

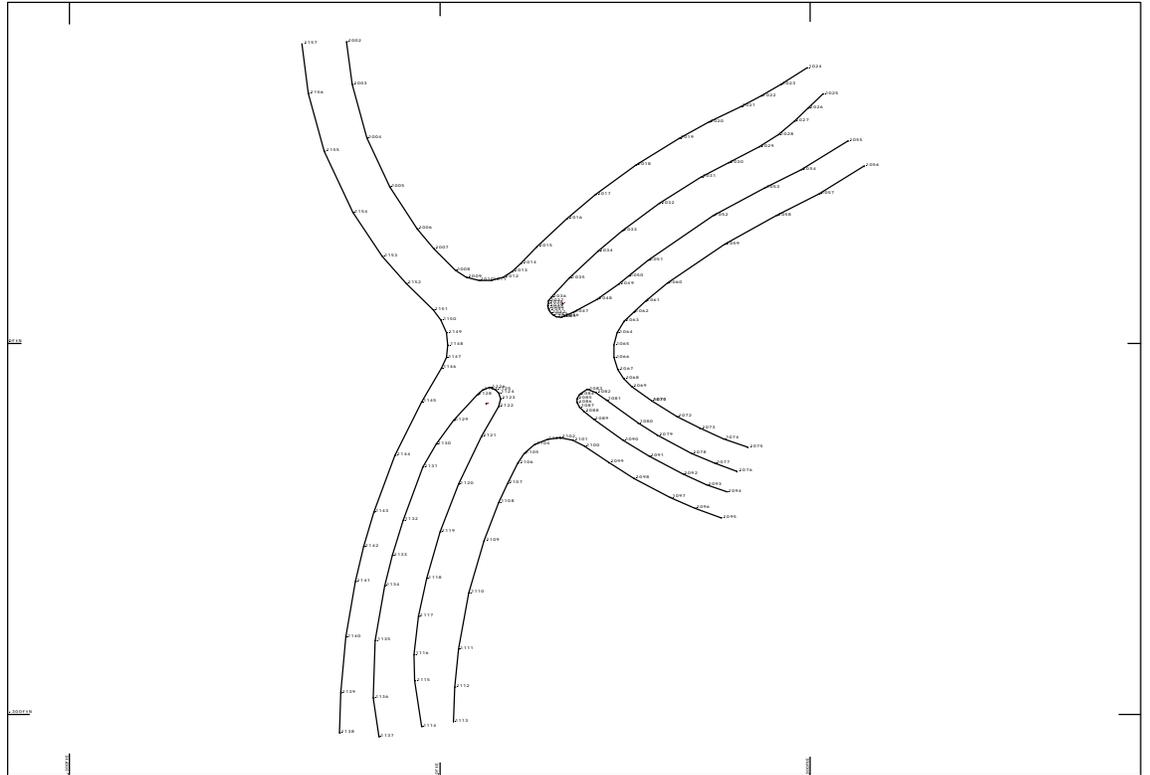
LTI Radial



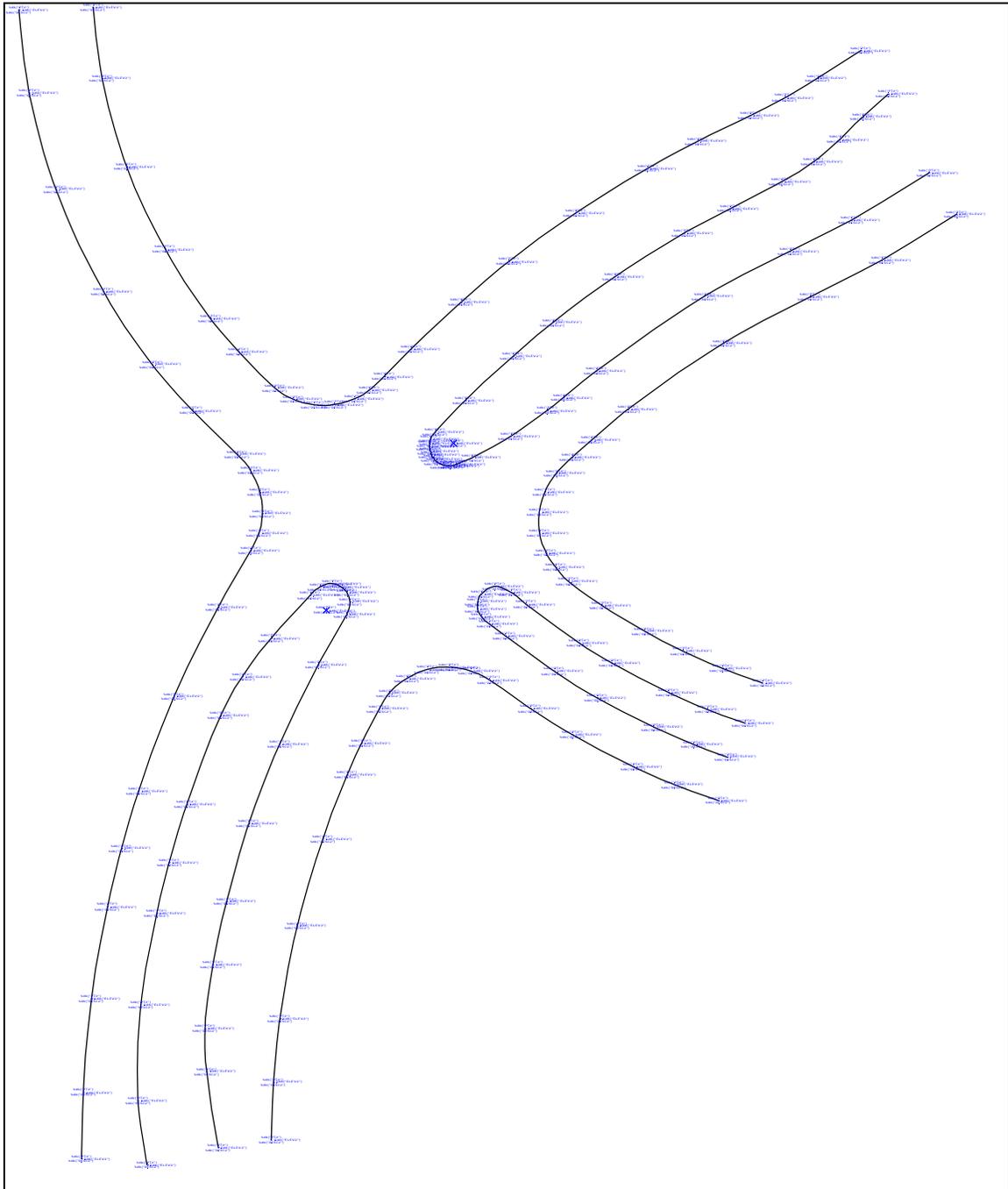
LTI Range



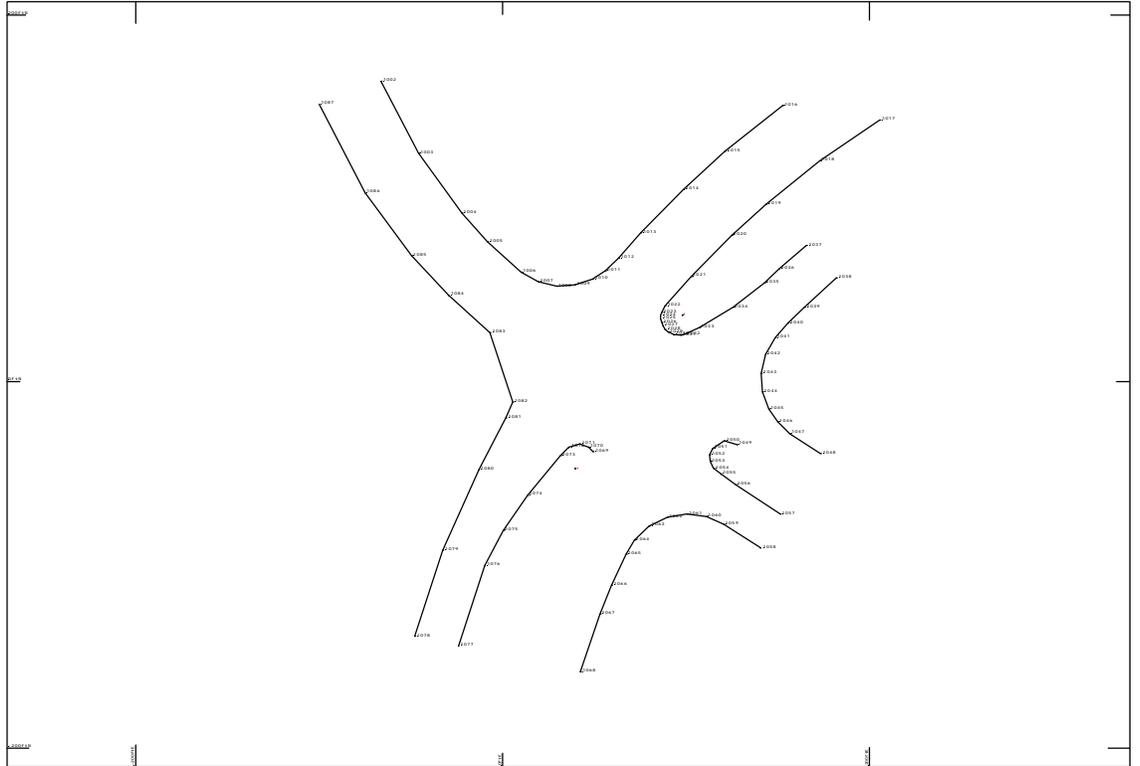
Sokkia 500



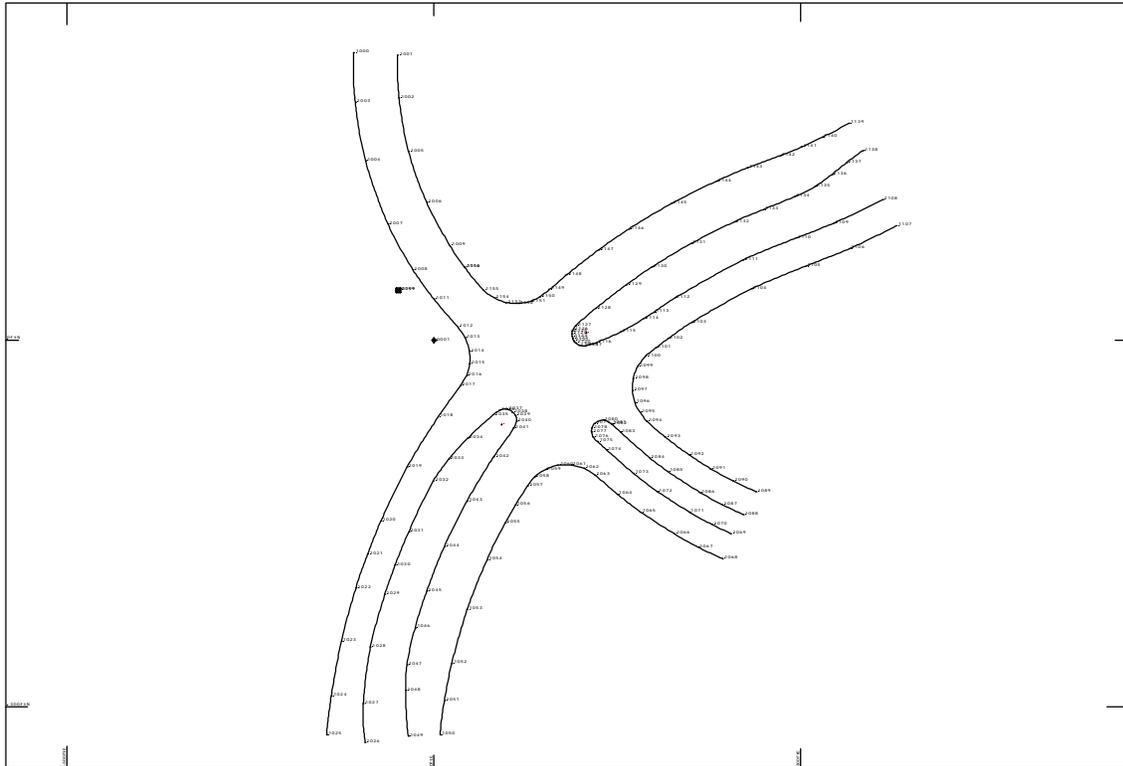
### Radian GPS



Sokkia 4110R



McKinzie & Associates

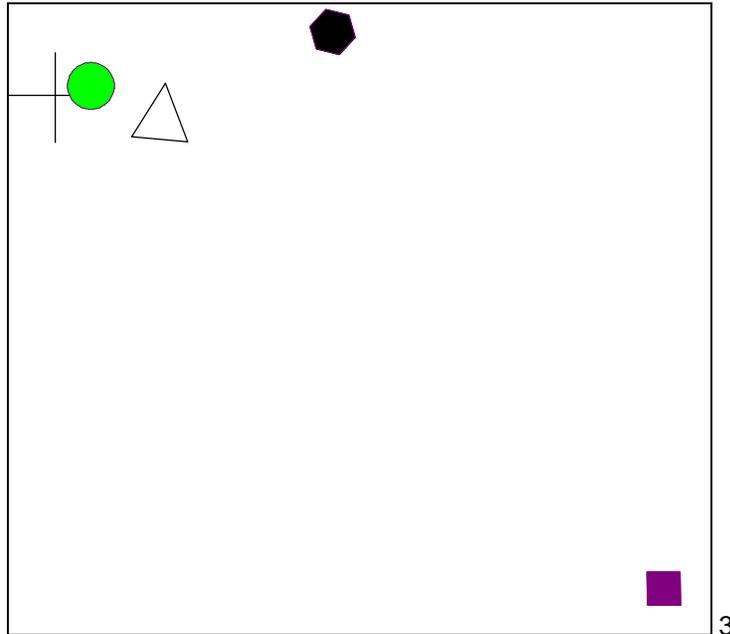
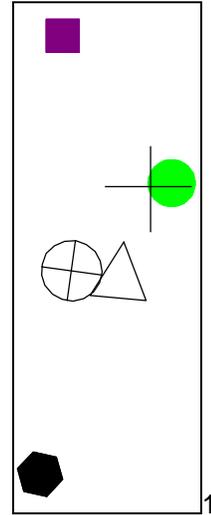
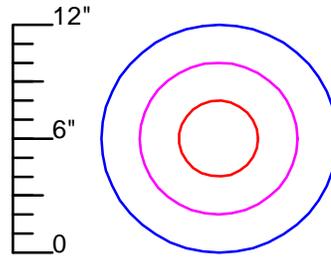


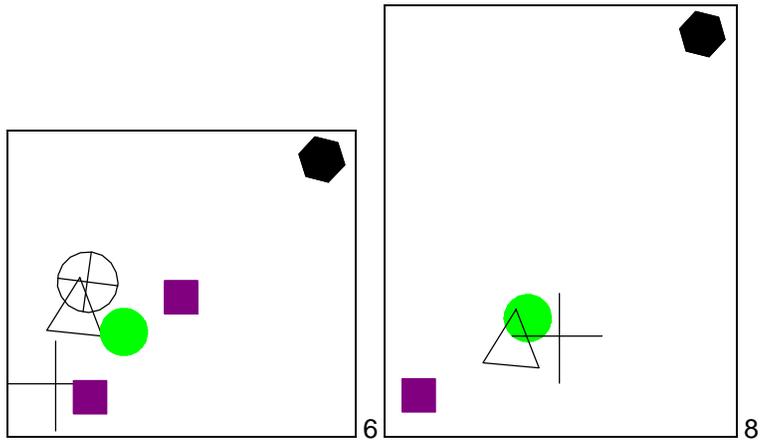
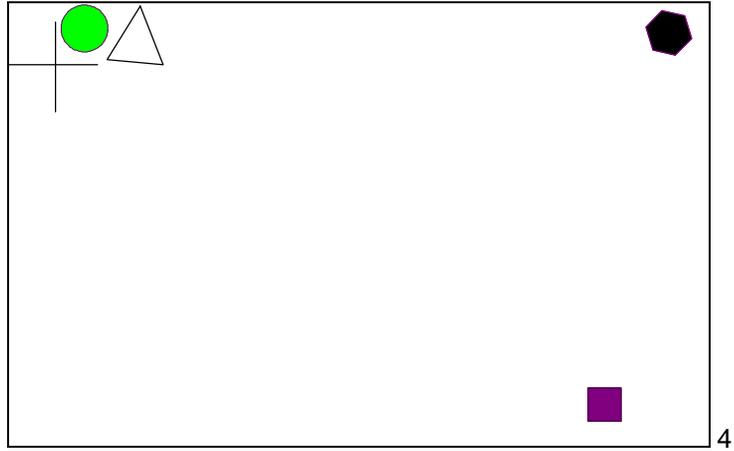
Line generation is provided by the mapping systems and operators and is not addressed in this analysis.

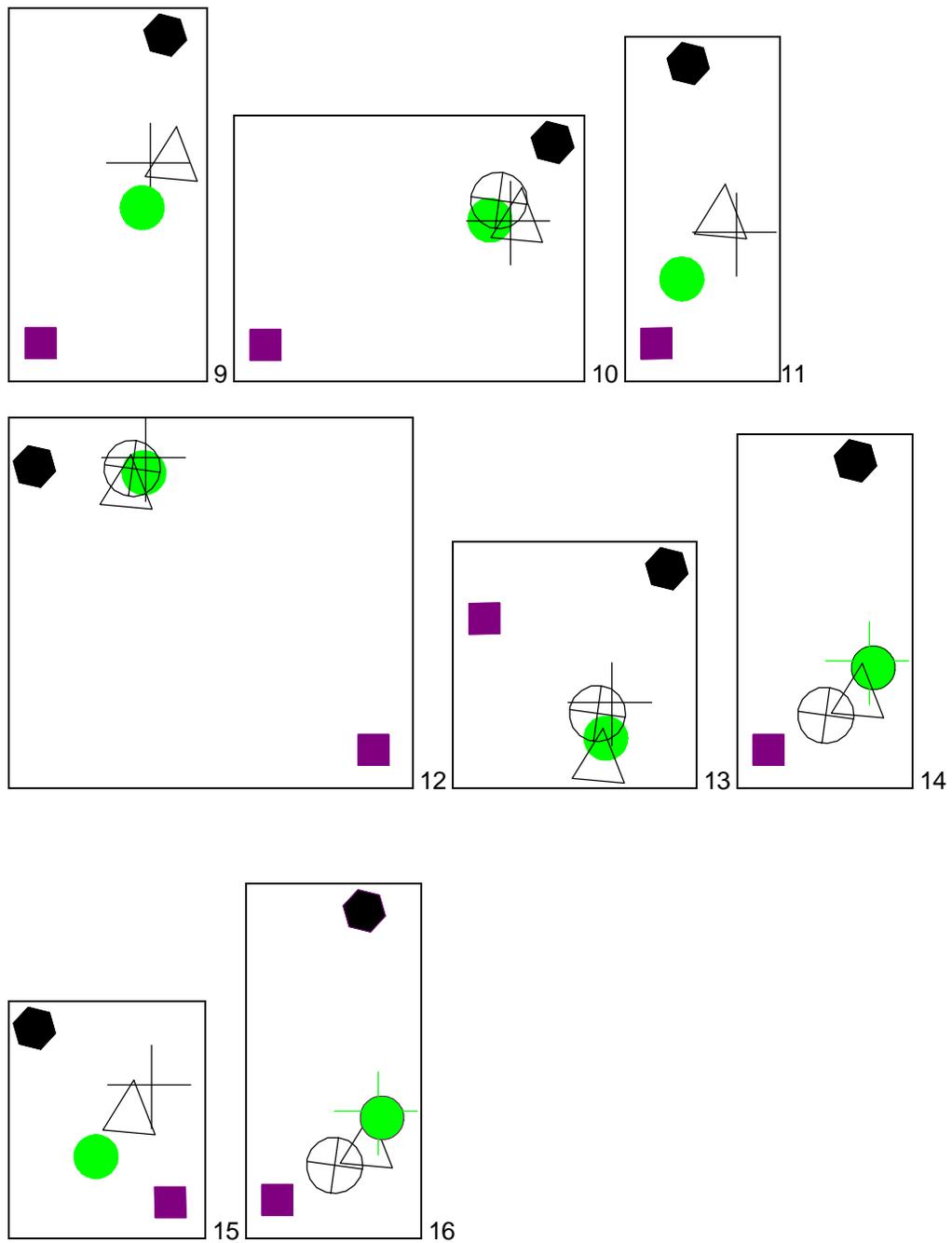
As an independent comparison, the project management team decided to complete an additional map. This map is produced using yet another total station.

## CHAPTER 6 - Graphical Accuracy Analysis

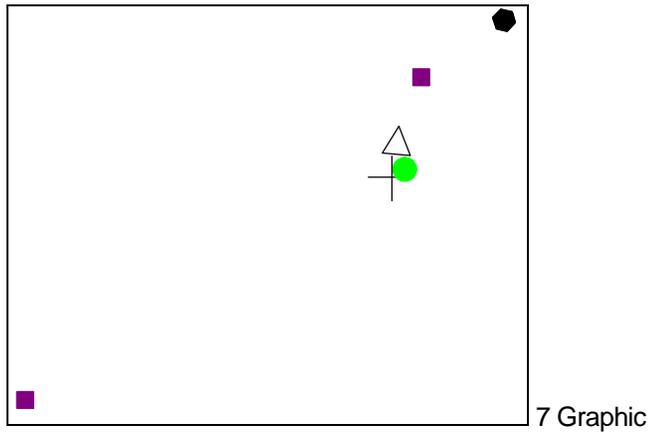
LEGEND	
■	LTI Range
△	Sokkia Total Sta.
●	Sokkia GPS
+	McKinzie & Assoc.
⬠	LTI Radial
⊕	Sokkia Reflectorless



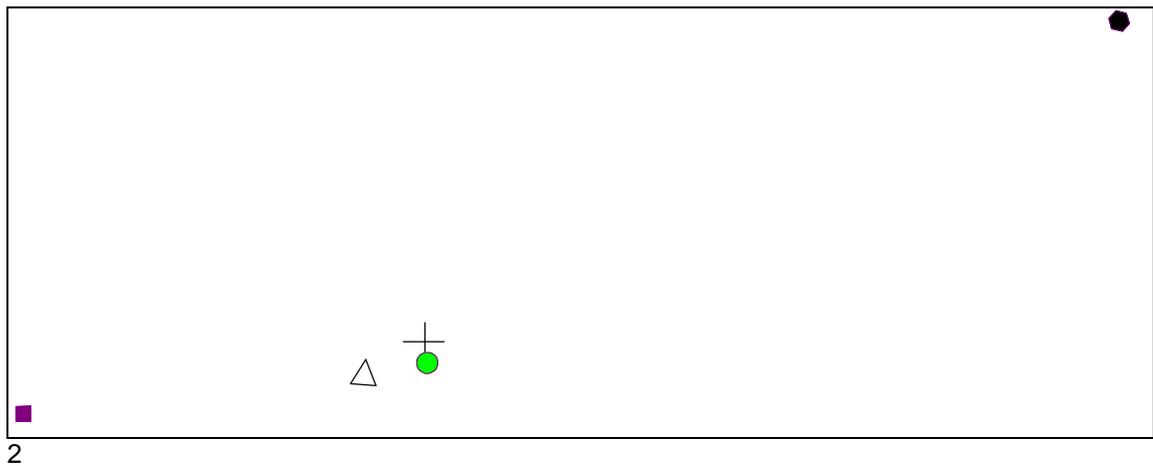




The prior fourteen WMF files were created from 1" = 4" scale drawings.



Graphic seven is generated from a 1" = 8" drawing



Graphic two is generated from a 1" = 16" drawing

As depicted in the above graphic, sixteen points were randomly selected for point comparison. Drawing exchange files are included in the data supplied.

## CHAPTER 7 - Test Results

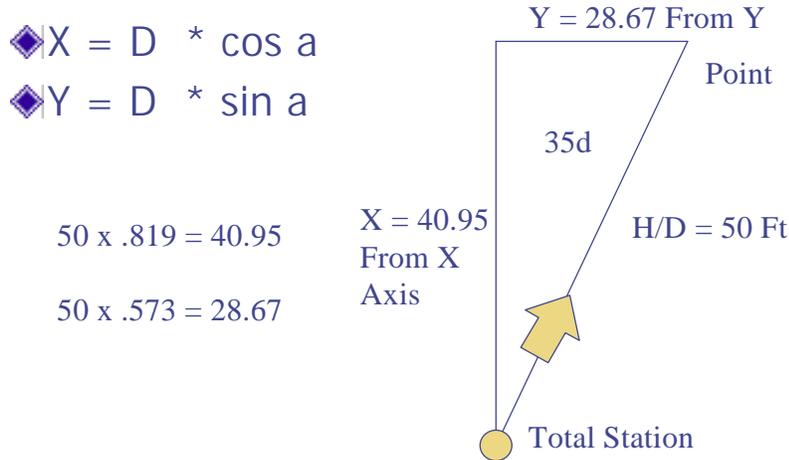
### Time

This exercise was not intended to be a time competition. Operator experience is a key element in quick mapping projects. Another ingredient in the fast documentation of points is disciplined communication between the station operator and the rod person. The GPS was clearly the fastest system. The

Subsequent additional map produced by the McKinzie Project team was completed in 64 minutes. The personnel however have the benefit of receiving the same training and operate under the same guidelines. This team experience allows them to operate as one unit. Speed can clearly be a matter of practice.

Accuracy

X,Y Point calculation



To validate the Polar coordinates to the Cartesian coordinates.

(All Total Station projects and LTI Radial Validated in this manner)

Step 1 Convert The Degree, Minutes, Seconds to degrees & decimal for V.Obs & H.Obs

Step 2 Calculate H.Dist by multiplying S.Dist by the SIN (V.Obs)

NOTE: Use COS (V.Obs) if angle is "0" in the horizontal position.

Step 3 Calculate the Northing by multiplying the H.Dist by the COS (H.Obs)

Step 4 The result is the number of feet from the X-axis.

Step 5 Calculate the Easting by multiplying the H.Dist by the SIN (H.Obs).

Step 7 The result is the number of feet from the Y-axis.

Your calculated X,Y (Northing, Easting) should match the values below.

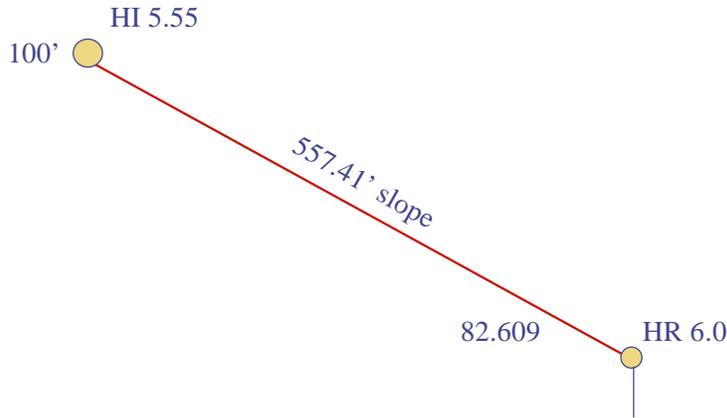
Note: For LTI Radial use COS (V.Obs) and to calc. H.Dist. Northing is Y and Easting is X on the raw data printout. Validation procedures work the same.

Pt #S	Dist	Vert Obs	Horz Obs	Code	North	East	Elev
2	57.9	90°08'24"	21°52'05"	BS	53.734	21.566	-0.141
1000	104.61	89°30'24"	71°59'57"	C	32.327	99.486	0.901
1001	61.66	88°54'11"	142°22'32"	C	-48.828	37.635	1.18
1002	255.46	90°26'52"	342°47'26"	EP1	244.016	-75.579	-1.996
1003	221.26	90°24'29"	341°13'45"	EP1	209.487	-71.196	-1.576
1004	176.75	90°17'37"	340°24'32"	EP1	166.516	-59.264	-0.906
1005	132.88	90°07'15"	342°09'21"	EP1	126.487	-40.718	-0.28
1006	94.67	89°59'48"	348°48'48"	EP1	92.871	-18.367	0.006
1007	76.86	89°58'45"	356°19'17"	EP1	76.702	-4.931	0.028
1008	60.52	89°59'49"	11°59'57"	EP1	59.198	12.582	0.003

1009	57.9	90°07'52"	21°50'27"	EP1	53.744	21.54	-0.132
1010	59.85	90°07'35"	31°49'39"	EP1	50.851	31.563	-0.132
1011	65.72	90°12'41"	39°13'46"	EP1	50.908	41.563	-0.242
1012	74.32	90°17'20"	43°42'00"	EP1	53.73	51.346	-0.375
1013	82.36	90°17'13"	45°15'31"	EP1	57.973	58.499	-0.412
1014	92.38	90°20'22"	45°32'17"	EP1	64.705	65.932	-0.547

## Point Elevation Calculation

$$\text{Pt. Elev.} = \text{I datum} + \text{HI} + (\text{S/D} * \cos(\text{vobs})) - \text{HR}$$



For this example, your datum elevation is set at 100 feet.

The HI or instrument height is set at 5.55 feet.

The HR or reflector height is set at 6.0 feet.

The Pt. Elev. equation to calculate is used to determine the point elevation

This is the distance above or below the datum.

$$\text{Pt. Elev.} = 100 + 5.55 + [557.41 * \cos(91^\circ 44' 30)] - 6.0 \quad (\text{Abbrev V.Obs})$$

$$\text{Pt. Elev.} = 82.62 \text{ to } 82.615$$

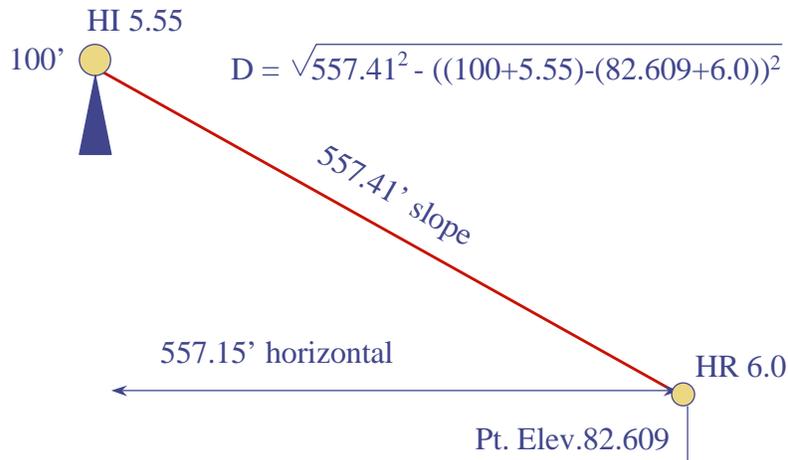
For the Data below the HI and HR are both 5.79 feet and the datum elevation is 0 feet.

$$\text{Pt 1002 Elev} = 0 + 5.79 + [255.46 * \cos(90^\circ 26' 52)] - 5.79$$

$$\text{Pt 1002 Elev} = -1.996$$

Pt #S	Dist	Vert Obs	Horz Obs	Code	North	East	Elev
2	57.9	90°08'24"	21°52'05"	BS	53.734	21.566	-0.141
1000	104.61	89°30'24"	71°59'57"	C	32.327	99.486	0.901
1001	61.66	88°54'11"	142°22'32"	C	-48.828	37.635	1.18
1002	255.46	90°26'52"	342°47'26"	EP1	244.016	-75.579	-1.996
1003	221.26	90°24'29"	341°13'45"	EP1	209.487	-71.196	-1.576
1004	176.75	90°17'37"	340°24'32"	EP1	166.516	-59.264	-0.906
1005	132.88	90°07'15"	342°09'21"	EP1	126.487	-40.718	-0.28
1006	94.67	89°59'48"	348°48'48"	EP1	92.871	-18.367	0.006
1007	76.86	89°58'45"	356°19'17"	EP1	76.702	-4.931	0.028
1008	60.52	89°59'49"	11°59'57"	EP1	59.198	12.582	0.003
1009	57.9	90°07'52"	21°50'27"	EP1	53.744	21.54	-0.132
1010	59.85	90°07'35"	31°49'39"	EP1	50.851	31.563	-0.132

### Horizontal Calculation



$$H/D = S/D * \sin(Vobs)$$

The Total Station records slope distance, horizontal distance is calculated. Using the formula above determine the horizontal distance for the four points below.

Horizontal distance = Sq. rt. Of the slope distance Sq'ed minus the datum plus the instrument height minus the pt. Elevation plus the reflector height.

OBS F1 001-1015	Dist 557.410	V.obs 91°44'30"	H.obs 10°16'20"	Code EP4
POS TP 1015	Nrth 548.222	East 99.354	Elv 82.609	Code EP4
OBS F1 0001-1016	Dist 555.690	V.obs 91°41'10"	H.obs 11°27'25"	Code FL2
POS TP 1016	Nrth 544.382	East 110.330	Elv 83.199	Code FL2
OBS F1 0001-1017	Dist 548.220	V.obs 91°43'25"	H.obs 13°49'15"	Code YL2
POS TP 1017	Nrth 532.107	East 130.903	Elv 83.061	Code YL2
OBS F1 0001-1018	Dist 546.120	V.obs 91°46'35"	H.obs 14°21'10"	Code EP3
POS TP 1018	Nrth 528.820	East 135.313	Elv 82.621	Code EP3

The LTI range triangulation method is validated by the following calculation

◆ Triangulation to xy Accuracy

- Distance between rp1 & rp2 must be known
- Distance from Pt1 to Rp 1&2 must be known
- $y = \sqrt{L_1^2 + D^2 - L_2^2}$      $x = \sqrt{L_1^2 - y^2}$
- 2D

## Data Comparison

With the validation procedure outlined above, point-by-point accuracy validation can be performed. Links to the following raw data files are provided for personal comparison.

[LTI Radial](#)

[LTI Range](#)

[Sokkia 500](#)

[Radian GPS](#)

[Sokkia 4110R](#)

[McKinzie & Associates](#)

## Elevation

The change of elevation of the projects varied from 1.57 feet for the Sokkia GPS to 7.85 feet on the LTI Range project. The area was checked with a level and showed the actual elevation change to be 4.90 feet. The McKinzie & Assoc. map had an elevation change of 4.92' the Sokkia total station map had a change of 5.00', the LTI Radial map was 5.93' and the Sokkia reflector-less total station map was 2.61'. It appears that the LTI Range project elevation was off as a result of no target height being used in the fourth control point setup. The raw data shows the target height at this point as 0.00 feet. This is a possible source for the error in the elevations. The Sokkia reflector-less project was not able to complete all point locations preventing it from obtaining the elevation change of the project since the highest and lowest elevations were at opposite ends of the project. GPS elevations are typically not as accurate as the northing and easting positions as is illustrated by the 3.39 feet of error.

The total station projects were the most accurate for change in elevation, followed by the LTI Radial, LTI Range and GPS. The Reflector-less project was not completed so the evaluation of its vertical accuracy is not possible.

## CHAPTER 8 - Future Trends

### Total Station

In the near future total station technology will refine forensic evidence documentation. We are just beginning to see the introduction of reflector-less products into the forensic field. These units for now have limited range. Range reduction compared to traditional units is a function of light more than model or brand. All electronic distance measuring relies on a portion of the transmitted light being reflected back to the receiver. The quality and quantity of the returned signal is a function of the target surface texture. Color of the surface is another consideration. With any reflector-less unit, line of sight is a critical function. These units for example usually operated by a single user experience difficulty seeing the opposite side of a curb or beyond a hedge. The more experienced station operator may move the unit to acquire points not visible from one occupied point. These units operated alone may never conquer this obstacle. Reflector-less units should not be viewed limited in this regard. The use of additional manpower as a rod-person defeats the reflector-less limitation.

The traditional total station is the workhorse of the forensic mapping field. As of late improvements in range and user interface make the operation simpler and quicker. The future for total stations rest in the robotic arena. Price as always, is a limitation for this technology to reach forensics. Only the most fortunate will see its use until a reduction in equipment cost occurs. Limitations exist in robotics such as tracking signal and speed.

### Laser

When first introduced, the “laser” was as a speed-determining tool. The tool garnered the laser label much the same way the automatic replaced the revolver. The evolution of this technology in forensics grew from base line and triangulation measuring to a more refined radial method. Obviously the benefit of single person operation is lost with the radial method. The future of the “laser” as a mapping tool is observed again in the robotic field. Returning the unit to a single man operation combined with the data gathered by the radial method is seen as a huge benefit to police users. Unfortunately the cost for research & development of this technology to the laser may make it as cost prohibitive as a robotic total station.

## **GPS**

The future is here, until you walk under a bridge or very large maple tree. The GPS system as seen here is fast and by all comparisons is quite accurate. The elevation data gathered may not be as critical to some type analysis of data as others. Considering the time code signals have traveled over 10,000 miles this accuracy is outstanding. The cost however is just as outstanding. The old adage “you pay for what you get” surely applies here. Just as the handheld GPS units entered the market at nearly \$1,000.00 each, now available for less than \$200.00 the survey accuracy GPS units price will likely come down. At any cost, when a crime scene or forensic site ranges over a very large area, this tool is the master of the box.

## **3D LASER SCAN**

The future in forensic mapping may truly rest with this new technology. Today three-dimensional laser scanning is available. In a highly abbreviated example of this technology, a user sets the instrument on a tripod, aims at the target area, sets the resolution, then activates the auto scan feature. Capturing up to 800 points per second, day or night the green-pulsed laser has a maximum range of 100 meters. A roadway surface scan can be completed in a matter of minutes. This system has been referred to as a robotic total station on steroids. This system refined to forensic work may truly take the jury to the scene. At \$125,000.00 per unit, cost again is a major factor. This technology may be a long time arriving at vehicular crash scene.

## **SOFTWARE**

We have examined the accuracy and systems of the tested units. The procedure for analyzing the data captured that is point geometry, other than in a raw format is vitally important. It is the goal of the forensic mapping community to not only capture where these points are, but also what they are. Then be able to present our data in a graphical format. Our task is that of assisting others in the understanding of the scene, site, drawing or map. This step is facilitated by a number of computer software products that read the data and assigned graphical attributes from which a map or forensic drawing is completed. These products range from the very simple to the very complex and expensive. The dividing line in complexity and cost is the axial aspect, 2D verse 3D.

Two-dimensional computer aided drawing programs run the lower end in cost. They may however be very functional and complex. Two-dimensional programs usually use only the X-Y coordinates of the three axis captured. This may introduce in some environments slightly shorter distances than the operator hoped to capture. Take for example a vehicle skidding over the crest of a hill. The rod person captures the beginning, and the end of the tire mark. The evidence has in reality moved over a vertical curve. The data however when analyzed in a 2D

program will not be able to calculate the true arc length. Only the point-to-point calculation for a straight-line distance will be performed. Three-dimensional programs add the zenith data (height or elevation) to our electronic environment. The example tire mark should be recorded at the beginning, several points along the path and the end for a more true travel distance.

Graphic handling is the ART in forensic mapping. Great care must be exercised in the final drawing product. All too often a very precise drawing or map is compromised by the introduction of incorrectly scaled graphics.

The best and brightest programmers develop these software packages based upon user evaluation and understanding of how the tool will be used. Not until recently have software companies reached out to the forensic field and asked what we needed. [MapScenes™](#) written by MicroSurvey of British Columbia Canada appears to be the first software program directed specifically at the forensic community. In the past, we have taken the pioneers approach and made programs functional. MicroSurvey is not associated with the manufacture or sale of measuring devices. Products of this caliber will lead the future of data and graphic handling in forensics.

## HUMAN

The forensic aspect of these systems necessitates recording the position and what is at that position. This is the critical difference that separates the Surveying community and Forensics. Training cannot be emphasized enough. Nearly anyone can learn to operate a total station or laser-measuring device. It is simply not enough to know how to operate the machine. The operator must accomplish an understanding of the system. An ability to articulate system functions is crucial. Lastly, and most important, the operator must possess some artistic ability in the final reduction of data to a drawing.

The operator must positively answer one simple question. Is this map a fair and accurate representation of what you saw at the scene? How fair seems to be a rather ambiguous term for such a precise process. How accurate the map is, clearly depends upon operator skill. The weakest link in the complete process is the rod person for a polar coordinate measuring system. The laser or reflector-less weak point is the operator's ability to know the measurement as indicated is what he intended. Repeatability of a measurement is as fundamental to electronic mapping as it is base line coordinate measurements with a roller wheel.

Finally, the human must apply the use of the newly found training. Disaster lurks minutes past the call to respond for a forensic mapping assignment, when training has not been practiced. Following a successfully completed course in Forensic Mapping, it is recommended students accomplish a demonstrated proficiency period. Over a period of up to eight weeks, students should participate in applying their training by completing at least one map or drawing per week. When do we quit learning?

## CHAPTER 9 - Conclusions

As can be seen from the presentation exhibits, each of the systems evaluated is capable of accomplishing a map. The level of detail and accuracy depends upon several topics. First, in a general way evaluation of accuracy must be addressed in how accurate the map must be. The forensic process does not make this judgment. Accuracy for blood spatter analysis requires a different level than does general crime scene or collision reconstruction. If one intends to evaluate the length of a skid mark for speed determination, length is not critical to the thousandth of a foot. Each of the systems is clearly capable of general length measurement. When the analysis turns to elevation or grade, more care must be exercised. The system operator and analyzer of the data must be expert in determining the level of accuracy the investigation warrants before it begins. Second, the level of detail is strictly dependent upon the training and expertise applied by the operator. Last of all, system comprehension, geometric observation and artistic ability play an important roll in the final analysis of a successfully completed map.

## CHAPTER 10 - Recommendations

For the current user, a high frequency of use is the best medicine for continued successful scene documentation. It is also recommended to establish a preventive maintenance schedule in accordance with your manufacturer. Keep abreast of the latest changes in software development.

The newcomer must still beware. When shopping, be sure you are buying a system capable of meeting your needs and not exceeding your personal capabilities. Look for a manufacturer who understands forensic mapping. You do not need equipment capable of measuring five miles to a single target. Select the level of accuracy your discipline requires. You do need quick, easy and reliable at an affordable price. Like shopping for anything, evaluate your representative, manufacturer, model and training offered. If training is not available specific to forensic mapping and its application to the judicial system, separate your equipment purchase and training demands.

Conversion of Polar coordinates to Cartesian coordinates can easily be validated. EDM measurements are not as easy to validate as light wavelengths and light travel times are not recorded. Applying the reference measurement protocol discussed previously can independently validate the distance measurements recorded. It is recommended this practice be adopted.

Work to understand your equipment and be prepared to explain its operation. It is not necessary for you to articulate how a pulsed infrared EDM calculates a distance. You should however know what it is and what it does.

Finally, electronic forensic mapping use continues to grow due to the persistent need of reliable and accurate evidence documentation. The application of this technology comes to play at some critical incident scene or site. Guard against becoming part of the critical incident. Every safety precaution should be exercised when utilizing your equipment.

## References

<http://www.lasertech.com/laserproducts/mapstarcm.html>

<http://www.sokkia.com/Radian/features.htm>

<http://www.trimble.com/gps/>

Texas A&M, TEEX, [Forensic Mapping](#) course manual