USE OF REMOTE SENSING FOR COLLECTION OF DATA ELEMENTS FOR LINEAR REFERENCING SYSTEMS

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Submitted to

The Iowa Department of Transportation

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1. EXECUTIVE SUMMARY

This report evaluates the use of remotely sensed images in implementing the Iowa DOT LRS that is currently in the stages of system architecture. The Iowa Department of Transportation is investing a significant amount of time and resources into creation of a linear referencing system (LRS). A significant portion of the effort in implementing the system will be creation of a datum, which includes geographically locating anchor points and then measuring anchor section distances between those anchor points. Currently, system architecture and evaluation of different data collection methods to establish the LRS datum is being performed for the DOT by an outside consulting team.

This research adds to that work by further evaluating the use of remotely sensed images for different components of the LRS. Specifically, the use of imagery for creation of the datum, including locating anchor points, locating business data, and measuring anchor sections; producing a spatial representation of the datum; and locating intermediate intersections along the datum were investigated. Four imagery datasets datasets were evaluated in the various portions of the studies. They included a 2-inch resolution dataset, 6-inch resolution dataset, a 24-inch resolution dataset, and a 1-meter resolution dataset. The 1-meter dataset simulated the best satellite data available commercially. Although a 2-inch resolution dataset was evaluated for several of the studies coverage in the images was limited so its evaluation was limited. Additionally, videologging consultants agreed to measure five of the test segments (located in Pilot Study Area 2) using a DMI and DGPS as part of pavement condition assessment they were conducting.

The first section (Section 2) of this report provides background information on remote sensing. Section 3 describes the datasets and pilot study areas. The fourth section discusses the use of imagery to establish the geographic locations of anchor points and business data. The actual spatial accuracy of the images is evaluated as well as how well features can actually be identified at different levels of image resolution. Additionally, the human error that may result due to variation in the manner that observers manually locate objects in images was evaluated and reported for the four image datasets. Section 5 investigated the accuracy with which the imagery and videologging methods could measure anchor section distances as compared to the Iowa DOT's Videolog DMI data that were collected as part of the Iowa DOT LRS Pilot Study. Next, the use of imagery and DGPS was evaluated for use in creation of a spatial representation of the datum. Finally, different methods were compared for calculation of the distance along anchor sections to intermediate, non-anchor point intersections. The imagery datasets and the use of GIMS cartography were discussed.

2. INTRODUCTION

The Iowa Department of Transportation is in the process of creating a linear referencing system (LRS) for the state of Iowa. A significant portion of the effort in implementing the system will be creation of a datum, which includes geographically locating anchor points and then measuring anchor section distances between those anchor points. Currently, system architecture and evaluation of different data collection methods to establish the LRS datum is being performed for the DOT by an outside consulting team. Data collection methods evaluated by the consulting team include:

- kinematic GPS
- videolog van DMI
- low-resolution orthophotos
- high-resolution orthophotos
- field inventory
- GIMS cartography
- project plans
- VideologVan DMI and GPS

This research adds to that work by extending the evaluation of remotely sensed images for different components of the LRS, including investigation of their use for locating anchor points and measurement of anchor section lengths. An additional evaluation of videologging was possible. A videolog vendor was completing a pavement condition assessment in Ames, Iowa and agreed to measure several anchor section lengths for several test sections using a DMI and DGPS.

2.1 Linear Referencing

Linear referencing locates objects (point events) in terms of their distance and direction along a segment from a known set of points. Linear events, such as a section of roadway with a homogenous surface type, may also be located using linear referencing.

A base datum will be created as part of the Iowa DOT LRS. The datum will consist of anchor points and anchor sections. Anchor points are geographic locations that establish the beginning and ending point for an anchor section. Anchor sections are distinct segments created by measuring the distance between a pair of FROM and TO anchor points. The datum will be created and anchor sections measured using the most accurate and cost effective method available, such as video-log vans. At the time this report was written a final method had not been selected.

Anchor sections per se have no spatial component. They only reflect a distance measure between two anchor points. However, it is expected that a spatial representation of the datum will be created which does have a geographic component. A spatial representation may be created using methods such as the video-log van with DGPS or digitizing high-resolution orthophotos.

2.2 Remote Sensing

Remote sensing is the science and art of acquiring information about objects from measurements made at a distance, without coming into physical contact with those objects (Lillesand and Keifer, 1994). The USGS defines remote sensing as a process of detecting or monitoring an area, usually from the air or from space, by measuring reflected or emitted radiation (USGS, 2001). Remote sensing is typically carried out using sensors mounted on a platform, which record the emitted, reflected and transmitted energy of an object on an image plane. Typical platforms used in remote sensing include satellite, aircraft, static ground observation, and vehicle mounted. The degree of response to the sensor depends on the intensity of the energy received, which in turn, depends on the distance of the sensor from the object.

For transportation applications, either ground based (vehicle or static) or air-based are the most common remote sensing methods, which is usually in the form of imagery. However, satellite imagery also is a viable source of data for some applications but maximum resolution is much lower than for aerial photography. With the advent of the IKONOS satellite, multi spectral and infrared images at resolutions as low as 1 meter are now commercially available.

There are many remote sensing applications in the fields of forestry, oceanography, geography, transportation, etc. Remote sensing has been used for planning, intersection studies, traffic studies, and inventory in transportation. Aerial photographs, videologs and photologs are some of the extensively used remote sensing technologies in transportation, especially for inventory purposes. Aerial photographs have been used in route optimization and parking studies as well as density and level of service studies. Satellite images have been used for tracking roadways, extracting inventory data, and for traffic engineering studies.

3. DESCRIPTION OF DATA AND PILOT STUDY AREAS

Several sources of data, including imagery datasets and GPS points, were used in various parts of the research. Three pilot study areas were used to evaluate various components. The following sections describe the datasets that were used in different applications as well as general descriptions of the pilot study areas.

3.1 Data Sources

Three orthophoto datasets of varying resolutions were available with coverage for all portions of the study areas. A fourth dataset with 2-inch resolution was available for one of the pilot study areas. All datasets were panchromatic.

3.1.1 One-Meter USGS/Simulated Satellite Imagery Dataset

A 1-meter resolution dataset was available from the Iowa State University Geographic Information Systems Support and Research Facility. The original source of the images was the USGS DOQQs. The images were taken in 1994 by the Western Mapping Center (WMC) and stored in Tagged-Image File (TIF) format. The 1-meter images are similar to the resolution available from the IKONOS satellite. As a result, the images were used to simulate the best satellite imagery data that is commercially available.

3.1.2 24-Inch Resolution Dataset

A 24-inch resolution ortho-rectified dataset was obtained from the Story County Planning and Zoning Department, Story County, Iowa. A consulting company, took the original photographs in 1998. The images were available in a digital format and stored in Multi-resolution Seamless Image Database (MrSID) format.

3.1.3 6-Inch Dataset

A digital dataset with 6-inch resolution was available from the Iowa Department of Transportation. These images were originally obtained by the DOT from the Story County Planning and Zoning Department, Story County, Iowa. The images were also from 1998. The 6-inch dataset was ortho-rectified, and stored in Tagged-Image File (TIF) format.

3.1.4 2-Inch Dataset

A 2-inch resolution dataset was derived from photographs available from the photogrammetric division of the Iowa DOT. The original photos were taken in the spring of 1999 by a commercial vendor for the Iowa Department of Transportation. The negatives were scanned using a commercial vendor, at 0.177-foot resolution and then georeferenced by the research team. Georeferencing consisted of the following steps:

- The scanned images were converted from compressed *jpeg* format to *tiff* format;
- The size of each image was reduced by trimming the borders using ERDAS Imagine so that images could be overlapped;
- Each image was georeferenced using at least 4 control points;

- Images were manipulated using ArcView Image Analysis and pyramid layer files (.rrd files) created for each image.

Pyramid layer files are created by image analysis software's, which store the image file attributes such as band information in a compressed file (*.*rrd* file) for faster display of images when magnified or reduced from their original size. The pyramid layer files created by ERDAS Imagine do not produce compatible pyramid layer information for use in ArcView. Images were georeferenced using GPS points collected for the Pilot Study Area 1 as described in Section 3.2.

3.1.5 Reference Points from Real Time Kinematic GPS

GPS data were used in several applications in this research. GPS points were necessary to georeference the 2-inch dataset as described in the previous section. They were also necessary to test positional accuracy as discussed in section 4.2. A kinematic GPS survey was contracted for with an independent engineering consulting firm to obtain planimetric coordinates for 55 selected points. The survey was performed using a Real Time Kinematic GPS unit, with a horizontal accuracy of 0.5 cm and vertical accuracy of 2 cm. The coordinates were obtained in the State Plane Iowa North coordinate system and NAD 1983 datum. In order to correct the GPS points collected, the kinematic method used a static survey system at one station (master) while another survey system (rover) moved from one station to the next until all locations were mapped. For each point collected, the rover occupied the position for 2 to 10 minutes. During the entire data collection session, both receivers continuously tracked the same satellites. Unlike differential GPS, where coordinate corrections are determined, the kinematic method uses a phase difference technique to determine the intersecting vectors. RTK systems can achieve sub-centimeter accuracy, free of cycle slips using four or more satellites ***(20, xxxx)***.

3.2 Pilot Study Area 1

The first pilot study area was along the US-69 corridor in the city of Ames, Iowa as shown in Figure 3-1. The study corridor included three roadway segments, South Duff Avenue, Lincoln Way and Grand Avenue. The length of the corridor segment was 4.1 miles and most of the surrounding land use was either commercial or residential. The corridor was selected in part since imagery from all four datasets was available for the area. Eight intersections located along the corridor and were included in the analysis. Two intersections off-corridor were also included in the pilot study since imagery was available for them as well.

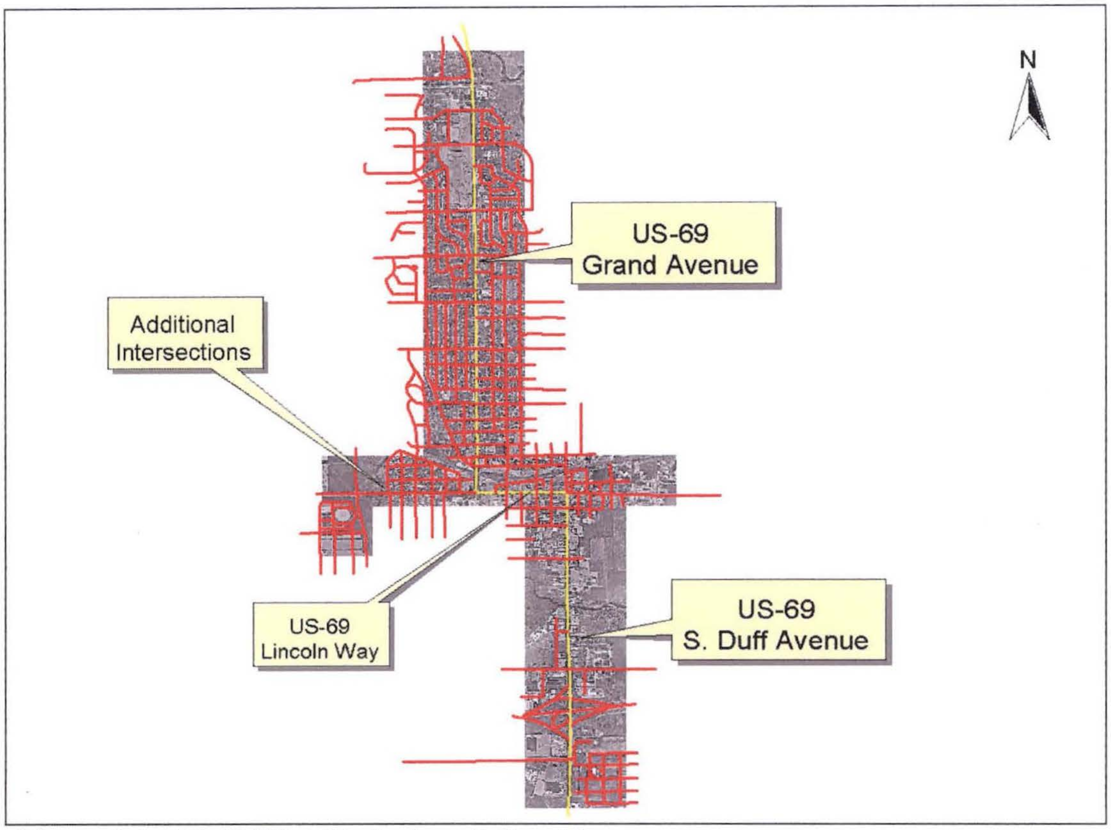


Figure 3-1: US-69 Pilot Study Area 1 Corridor

3.3 Pilot Study Area 2

A second pilot study in Ames, Iowa was selected that included seven test roadway segments. Segments were selected from those included in the pilot study area selected by the Iowa DOT for their LRS Pilot Study as shown in Figure 3-2 (Image courtesy of the Iowa DOT). Locations within the DOT study area were selected because VideoLog DMI measurements were available for those segments. Segment lengths had been measured using the DMI as part of the Iowa DOT LRS project and were available for comparison. Segments for Pilot Study 2 were also selected to represent a variety of geometric conditions. Several were characterized by fairly significant changes in vertical profile. Others had significant changes in horizontal alignment. Segments varied from 0.4 to 2.6 miles in length. The seven different locations for Pilot Study Area 2 are shown in Figure 3-3. All locations were in Ames, Iowa in Story County.

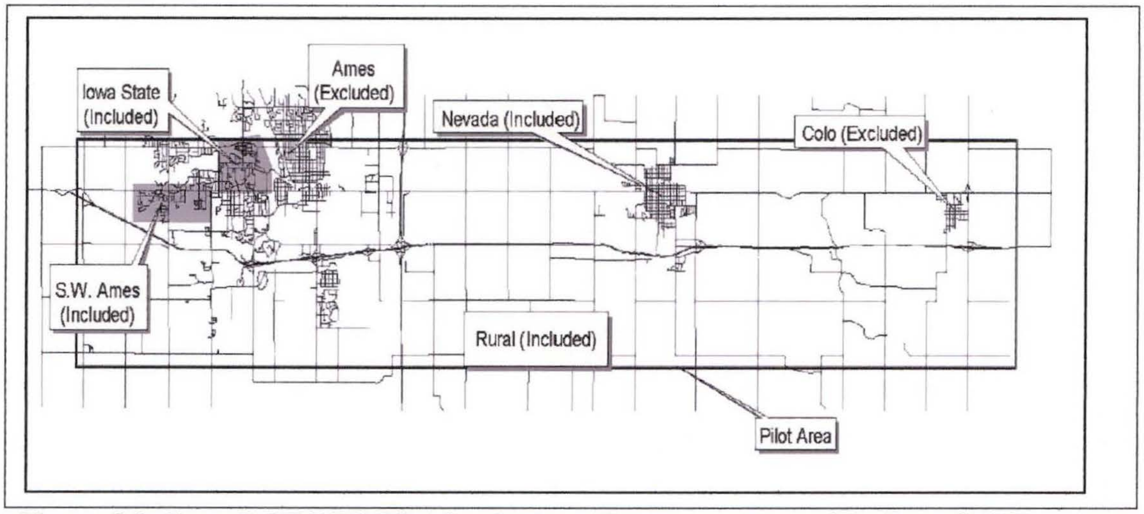


Figure 3-2: Iowa DOT LRS Pilot Study Area (Image courtesy of the Iowa DOT)

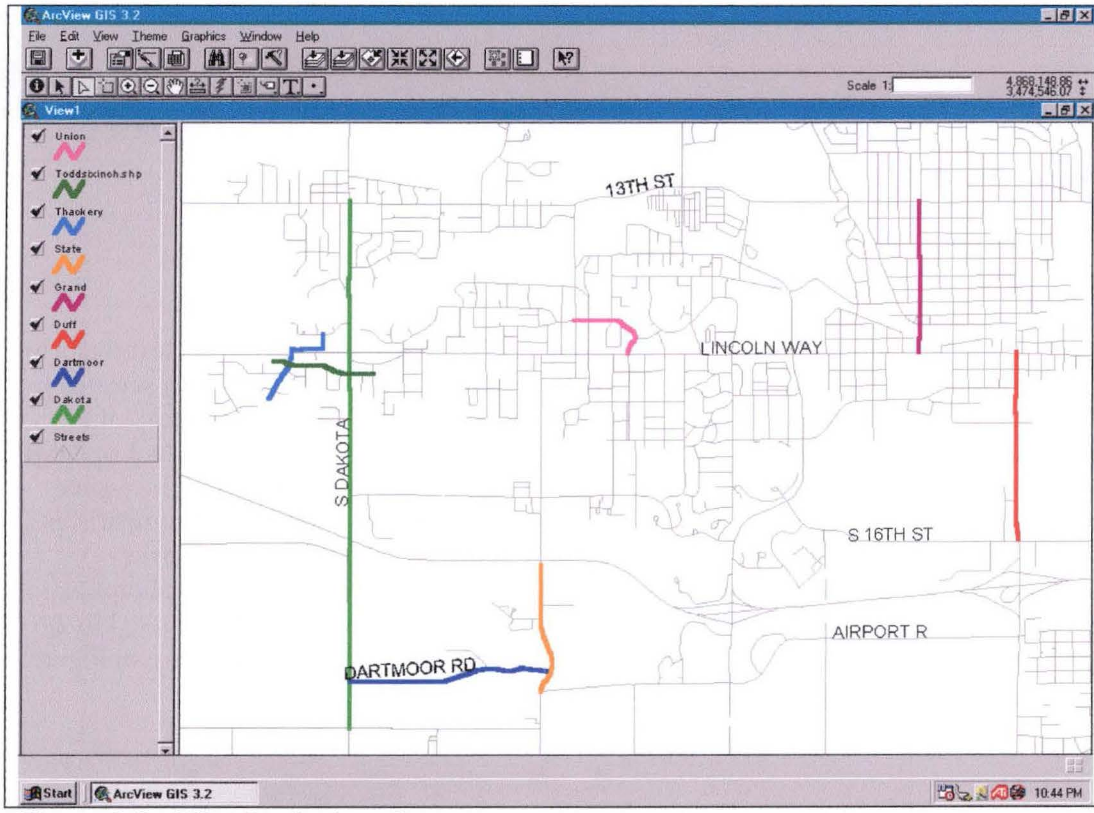


Figure 3-3: Pilot Study Area 2

3.4 Pilot Study Area 3

The third pilot study area also contained six test roadway segments that are located within the boundaries of the pilot study conducted by the Iowa DOT LRS project team as shown in Figure 3-1. Pilot Study Area 3 was part of the pilot study for another research project and was included since several portions of the research were similar to this project. All segments were located either in Ames or Nevada in Story County, Iowa as illustrated in Figures 3-4 and 3-5.

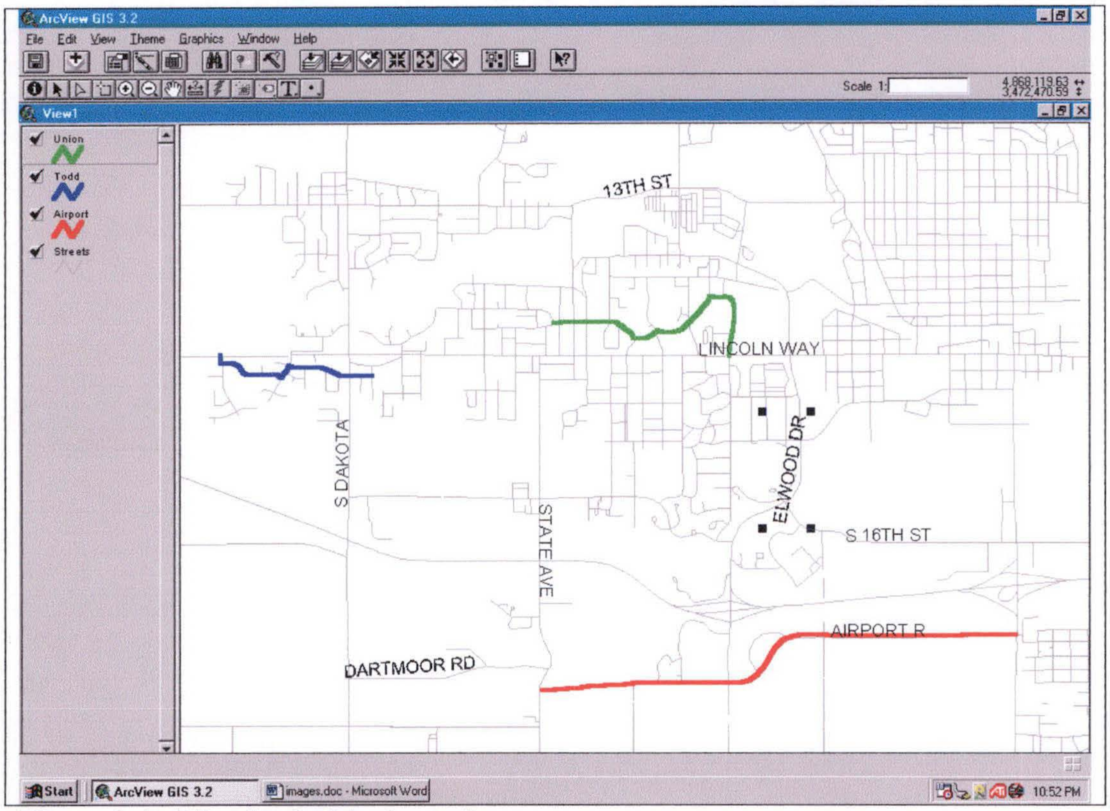


Figure 3-4: Pilot Study 3 in Ames, Iowa

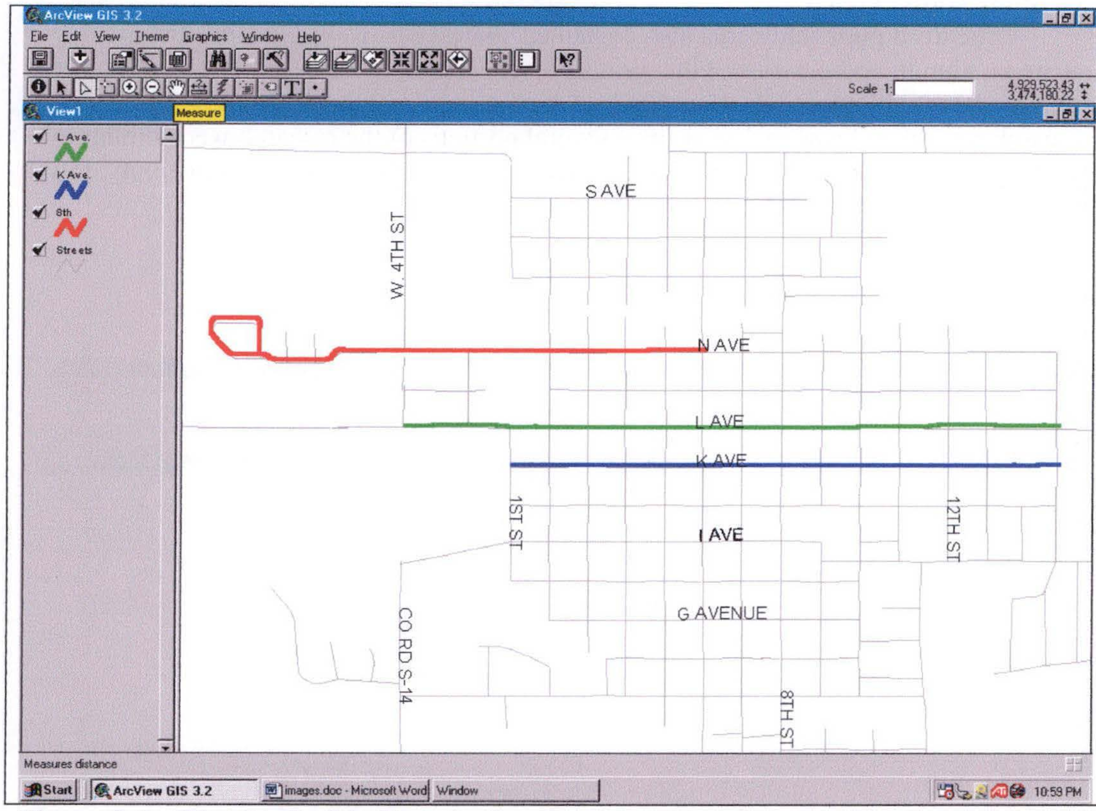


Figure 3-5: Pilot Study 3 in Nevada, Iowa

4. USE OF IMAGERY FOR ESTABLISHING THE GEOGRAPHIC LOCATION OF ANCHOR POINTS AND BUSINESS DATA

Anchor points mark the spatial location that marks the "begin" and "end" (TO and FROM) of an anchor section. They need to be located geographically. This entails either using some type of GPS (kinematic, videolog GPS, etc.) or some other method that allows geographic placement. The accuracy and usefulness of using aerial or satellite imagery for establishing the position of anchor points, as well as other types of roadway features was evaluated and is presented in the following sections.

4.1 Feature Recognition

The ability to determine the location of an anchor point or business features using remotely sensed imagery, depends on whether or not they can be correctly identified in an image. Feature recognition is a measure of whether a particular feature can be identified at all and whether it can be identified consistently. Feature recognition was evaluated for each of the four image datasets. Identification Percentage (IP), was the measure of effectiveness used to evaluate the how well and how consistently features could be identified in the various datasets. IP was calculated using:

$$IP\ (\%) = (F_a/F_g) * 100 \tag{4-1}$$

where:

IP = percent of features identified in images compared to actual number of features present in the field

F_a = number of features identified in imagery datataset

F_g = actual number features present in the field

For example, an IP of 95% for traffic signals at 6-inch resolution means that 95% of the total number of signals present on the ground were recognized in a particular dataset.

4.1.1 Methodology

Locations within Pilot Study Area 1 (described in Section 3.2) were used as test sites to evaluate feature recognition. A set of twenty-two roadway features was selected including signs, number of right turn lanes, median type, drainage structures, and bridges. ArcView 3.2 was used to display images for each of the four datasets. Features were manually identified in the images. In many cases a feature could be directly identified. This was especially true for the higher resolution datasets. Feature recognition also depended on photo interpretation. For example, a drainage box may be identified based on the shape (a distinct rectangle), color (white or light gray), and location (along the side of a road).

Features selected for identification were based on those currently collected by the Iowa Department of Transportation and those required for collection by the Highway Performance Monitoring System (HPMS). In order to be included in the list, several occurrences of a specific feature in the study area were necessary (i.e. several railroad crossings would have to be present before railroad crossings were included as a feature for testing). Features were first identified in each imagery dataset and then a site study was conducted to collect the actual number of each feature present in the field. Except for the number of driveways present, no features were falsely identified in the images that were not present on the ground (no over counting). The number of driveways was over-estimated in the 6-inch dataset. A single continuous driveway appeared as two separate driveways in the images in two different instances resulting in overestimation of driveways.

Sample sizes for a particular feature were not consistent across the four datasets for various reasons. In several instances, geometric changes in the roadway had occurred between the time that the 1-meter photos were initially taken (1994) and the time that the research was conducted. These locations were discarded, resulting in lower sample sizes for several features in the 1-meter dataset. Sample size was also reduced due to the object under consideration being blocked from view in the imagery. Vegetation obstructed several objects in the 6-inch dataset as shown in Figure 4-1. When this occurred, the obstructed feature was dropped from both image and field counts also causing a smaller sample size. The 2-inch dataset was flown at a lower altitude so the images covered less area than the other datasets. This also resulted in fewer features in several categories for that dataset.

Figure 4-1: Underestimation of signals due to vegetation cover

4.1.2 Results

Results for Identification Percentage are provided in Table 4-1. As shown, most features could be consistently identified in the 2-inch and 6-inch datasets. Identification percentage was greater than 100% for driveways for the reasons stated previously. It should also be noted that the results were calculated using manual identification of features with panchromatic digital images. Although beyond the scope of this research, improved results may be obtained using color images, hyperspectral analysis, sub-pixel analysis or automated processes. The inability to distinguish various features may also have resulted from distortions in the photos, atmospheric conditions at the time the images were taken (sun angle, haze, etc), quality of the equipment used, etc. rather than being entirely a function of the resolution of the images. However, the results do give an indication of how well objects can be identified and how consistently objects can be identified for images of different resolutions.

The number of features actually collected on-site, the number of features identified in the images, and the calculated Identification Percentages are presented in Table 4-1 for each dataset. Sample sizes vary between datasets for various features for the reasons discussed in Section 4.1.1. The sign category included stop signs, speed limit signs, and information signs. Driveways included both commercial and residential driveways and the bridge category included both roadway and railroad bridges.

As shown, only major features, such as location of intersections, land use, general intersection geometry, location of railroad crossings and number of railroad tracks, could consistently be identified in the 1-meter dataset. Additionally, a number of features could not be identified at all, including traffic signals, drainage structures, and utility poles. Other features, such as the presence and number of left and right-turn lanes, could be identified but not consistently.

Results improved only slightly for the 24-inch dataset. Identification Percentage increased for driveways and number of bike lanes. Utility poles, which could not be seen at all in the 1-meter dataset, could be identified in the 24-inch images but not consistently. A number of features could either not be identified at all or were not identified consistently.

Results were significantly better for the 6-inch dataset. All features could be recognized. Only signs, type of median, location of on-street parking, location of intersection stopbars, and utility poles could not be consistently identified. In the 2-inch dataset, most features could be recognized consistently. Only signs and on-street parking had an IP of less than 100%. Signs in general are difficult to identify from an aerial view. The location of on-street parking and the presence of turning lanes, pedestrian crossings, and intersection stopbars are highly dependent on pavement markings, therefore identification may have been a function of how recently pavement restriping had been undertaken, although this could not be quantified.

Most of the features evaluated are more appropriate to what would be included in the LRS as business features rather than anchor points. However, the location of intersections, railroad track crossing, and the begin- and end-point of medians and bridges are features used as anchor points in the LRS design documentation. All features that may be used as anchor points, except medians, could be consistently identified in all datasets. Medians could not be consistently identified in either the 1-meter or 24-inch dataset. However, prominent types of medians (raised medians or those with vegetation) are easier to identify and are more likely to be consistently identified than other types, such as flush medians that are delineated only by pavement markings.

4.2 Positional Accuracy

Section 4.1 discussed whether items could actually be seen and consistently identified based on the various resolution of images tested. This section evaluates the positional accuracy of each dataset in terms of collection of both anchor point and business feature locations.

Positional accuracy is how closely the coordinate descriptions of objects in a particular spatial dataset compare to their actual location. A variety of factors influence the positional accuracy of digital geospatial data. Errors can be introduced by digitizing methods, source material, the specifications of aerial photography such as resolution, aerotriangulation techniques, ground control reliability, photogrammetric characteristics, and resolution and processing algorithms. Individual errors from these sources may not be significant, but collectively may significantly affect data accuracy. The National Standard for Spatial Data Accuracy (NSSDA) provides a method for estimating the positional accuracy of digital geographic data. The national standards and the tests are explained in the Section 4.2.2.

4.2.1 Specifications for LRS

Anchor points, locations that mark the beginning and ending point of a section of roadway know as an anchor section, must be spatially located to within ± 1 meter (3.28 feet) according to the Iowa DOT LRS Pilot Study (GeoAnalytics, December 2000). Anchor sections must be located to ± 2.1 meters (± 6.9 feet). The method used to locate business data to a LRM should be able to do so within ± 10 meters at 90% (± 32.81 feet).

4.2.2 National Standards for Spatial Data Accuracy

The National Standard for Spatial Data Accuracy developed a statistical testing methodology for estimating the positional accuracy of digital geospatial data with respect to georeferenced ground positions of higher accuracy *(18)*. This test applies to any georeferenced digital geospatial data in raster, point or vector format, which are derived

Table 4-1: Results of Feature Recognition

Feature	2 inch			6 inch			24 inch			1m (simulated satellite)		
	# of Features Identified			# of Features Identified			# of Features Identified			# of Features Identified		
	Image	Ground	IP (%)	Image	Ground	IP (%)	Image	Ground	IP (%)	Image	Ground	IP (%)
Signs	65	68	96	33	68	49	0	68	0	0	68	0
Signals	44	44	100	42	42	100	0	44	0	0	44	0
# of Intersections	20	20	100	22	22	100	22	22	100	22	22	100
Intersection Geometric Design	10	10	100	10	10	100	10	10	100	6	6	100
Intersection Land use	10	10	100	10	10	100	10	10	100	6	6	100
# of Right Turn Lanes	13	13	100	13	13	100	7	13	54	4	7	57
# of Left Turn Lanes	20	20	100	20	20	100	12	20	60	3	9	33
Railroad Crossings	4	4	100	4	4	100	4	4	100	4	4	100
# of Tracks at RR Crossings	7	7	100	7	7	100	7	7	100	7	7	100
# of Driveways	155	155	100	159	155	**103****	112	155	72	49	80	61
# of bicycle lanes/sidewalks	36	36	100	41	41	100	37	41	90	12	41	29
Medians	9	9	100	9	9	100	5	9	56	4	6	67
Median Type	9	9	100	7	9	78	1	9	11	0	6	0
# of TWLTL	1	1	100	1	1	100	0	1	0	0	1	0
Bridges	5	5	100	5	5	100	5	5	100	5	5	100
Pedestrian Crossings	16	16	100	16	16	100	0	16	0	0	16	0
Pedestrian Islands	3	3	100	3	3	100	1	3	33	1	3	33
Stop Bars	20	20	100	16	20	80	0	20	0	0	12	0
On Street Parking	19	20	95	19	20	95	11	20	55	12	20	60
Drainage Structures	14	14	100	14	14	100	0	14	0	0	14	0
Utility Poles	147	147	100	113	147	77	33	147	22	0	147	0

** The number of driveways was overestimated in the images from sources such as aerial photographs, satellite imagery and ground surveys. A data set's accuracy is evaluated by comparing the coordinates of several points, which can easily be located in both the test and independent data set of greater accuracy. Well-defined points must be used for comparison. Features like utility access covers, intersections of sidewalks, curbs or gutters make suitable test points (FGDC, 1998). The independent data set of higher accuracy can be any data set whose accuracy is predefined, such as a GPS survey or geodetic control survey.

Twenty or more test points are required to conduct a statistically significant accuracy evaluation, regardless of the size of the data set or area of coverage (FGDC, 1998). The standard does not provide any threshold accuracy values, but will only report the accuracy of the data set. The resulting positional accuracy should be reported in the same units as that of the source data set, which allows for comparison of different resolutions.

The Federal Geographic Data Committee recommends that any geospatial data be tested for horizontal and vertical positional accuracy. These accuracies are tested using Root Mean Square Error (RMS) test and the NSSDA. The NSSDA is a confidence interval for the RMS. RMS is the square root of average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points (FGDC, 1998). This test is performed both in X and Y directions in the horizontal plane for horizontal accuracy. Vertical accuracy is calculated by performing an RMSE test in the Z direction but was not tested for this research. The equations used for RMSE calculations are:

$$\mathrm{RMS}_x = \sqrt{\frac{\sum\left(X_{\mathrm{data,i}} - X_{\mathrm{check,i}}\right)^2}{n}} \tag{4-2}$$

$$\mathrm{RMS}_y = \sqrt{\frac{\sum\left(Y_{\mathrm{data,i}} - Y_{\mathrm{check,i}}\right)^2}{n}} \tag{4-3}$$

Where:

$x_{\mathrm{data,\,i}}$, $y_{\mathrm{data,\,i}}$: are the coordinates of the i^{th} datapoint in the dataset

$x_{\mathrm{check,\,i}}$, $y_{\mathrm{check,\,i}}$: are the coordinates of the i^{th} datapoint in the independent source of higher accuracy

n : is the number of datapoints tested

i : is an integer ranging from 1 to n

If the RMS is assumed to be the same in X and Y directions then the total RMS is calculated based on the following equation:

$$\mathrm{RMS}_r = \sqrt{RMS_x^2 + RMS_y^2} \tag{4-4}$$

Any variation in the data set such as uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the data set are taken into account by the NSSDA value. The NSSDA value is the 95% confidence value of the accuracy, which is calculated using the equation:

$$NSSDA = 1.738 * RMS_r \tag{4-5}$$

The Circular Map Accuracy Standards (CMAS) is similar to the NSSDA but provides a 90% confidence interval. CMAS is calculated using the equation (FGDC, 1998):

$$CMAS = 1.5175 * RMS_r \tag{4-6}$$

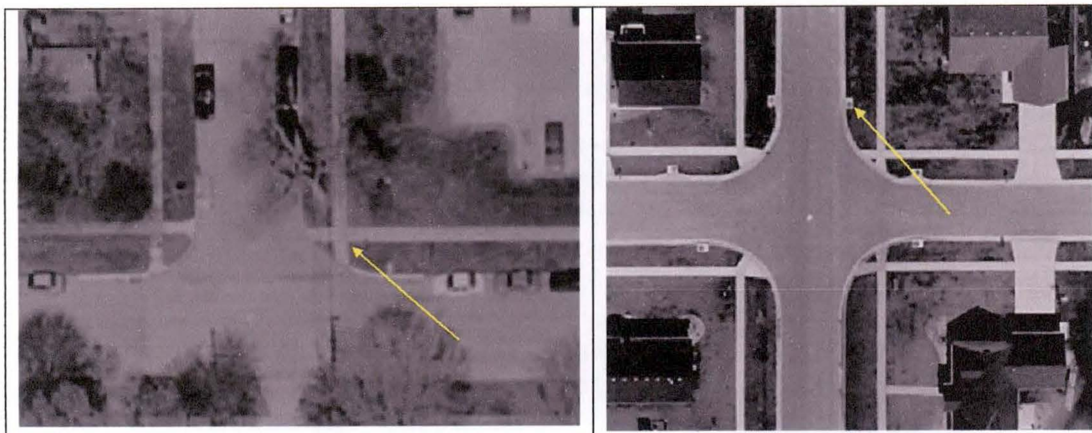
4.2.3 Methodology

The 2-inch, 6-inch, 24-inch and 1-meter resolution aerial photographs were tested for positional accuracy in the horizontal direction. Two sets of features, which could be represented as points and could also be seen in all four datasets, were selected for testing. The selected features were the southeast corner of two intersecting sidewalks and the southeast corner of drainage structures, as shown in Figure 4-2. To provide an independent dataset of higher accuracy, a Kinematic GPS survey was contracted for with an independent engineering consulting firm. The GPS dataset, which consisted of planimetric coordinates for the 55 selected points, was described in more detail in Section 3.1.5.

For the 6-inch dataset all 55 points were located and matched. In the 24-inch dataset only 37 of the 55 points could be identified in the images enough to be located. In the 1-meter aerial photographs, only 25 points could be identified. The 2-inch dataset also had fewer points available for comparison since 29 of the GPS points were used to georeference the images. This left only 26 points that could be used to test positional accuracy for the 2-inch dataset.

The GPS points were referenced with a unique id and matched to their corresponding point located in each of the four datasets. RMS and corresponding confidence interval tests were performed resulting in a measure of the error for each dataset. The complete calculations and test results are provided in Appendix A.

Table 4-2 summarizes the results for all the four datasets. The values are the 95% confidence percentages, indicating that 95% of the time the data points were within the NSSDA value of its location as defined by kinematic GPS. For example, the horizontal location of any well-defined feature in 6-inch resolution will be within 1.19 meter of its location, 95% of the time.



Intersection of side walks	Drainage structure

Figure 4-2: Southeast corners of features used for comparison

Even in the 1-meter datasets, 95% of points were located within 3.3 meters (10.84 feet) of their true location. This accuracy may be sufficient for a number of applications such as sign location, provided they can actually be identified.

Table 4-2 summarizes the results of RMS and Circular Map Accuracy Standards (CMAS) for all four datasets. The CMAS values are 90% confidence percentages, which means that 90% of the time the data points were within the CMAS value of their location as defined by kinematic GPS.

The 2-inch, 6-inch, and 24-inch datasets met the accuracy requirements for anchor points according to the Iowa DOT LRS specifications of ± 1.0 meter RMS. The 1-meter dataset had a RMS of 1.9 and exceeded the specifications. Similar results were reported by the Iowa DOT LRS Pilot study for both high (6-inch) and low (24-inch) resolution orthophotos (GeoAnalytics, et al, 2001). The DOT pilot study reported results for an

Table 4-2: Positional Accuracy Values for Each Dataset

Dataset	Error (meter)				
	Mean	Standard Deviation	RMS	CMAS (90%)	NSSDA (95%)
2-inch	0.2	0.2	0.3	0.4	0.5
6-inch	0.7	0.1	0.7	1.0	1.2
24-inch	0.8	0.4	0.9	1.4	1.6
1-meter	0.5	0.3	1.9	2.9	3.3

adjusted dataset that rejected large differences. Positional accuracy was calculated using high-resolution orthophotos coordinates for anchor points and those collected using kinematic GPS coordinates as well. The study reported a mean of 1.7 m, a standard deviation of 1.5 m, and an RMS of 2.2 meters for the high-resolution images. The Iowa DOT LRS Pilot study also reported a mean of 1.0 m, a standard deviation of 0.6 m, and an RMS of 1.1 meters for one operator and a mean of 0.9 m, a standard deviation of 0.5 m, and an RMS of 1.0 m for a second operator for low-resolution orthophotos.

4.3 Variation Between Observers in Establishing Spatial Position

In order to manually locate a feature on an image, the feature must first be identified and located by an observer. Even if standard procedures are provided for the identification of a feature and selection of its location, there can be differences among observers in locating the same point. If there is significant variation between where different observers locate a feature and if a number of observers are involved in reducing data, significant variations in locating features will result regardless of the accuracy of the data collection method. Variation can be attributed to differences in how objects are perceived in an image, observer experience in photo interpretation, and the care taken in locating a feature. Further, as the resolution of aerial photographs decreases, objects in the images are less distinct, which may also result in variation in locating a feature. An illustration of the differences that result in locating an object by different observers and the resulting mean and standard deviation are shown in Figure 4-3.

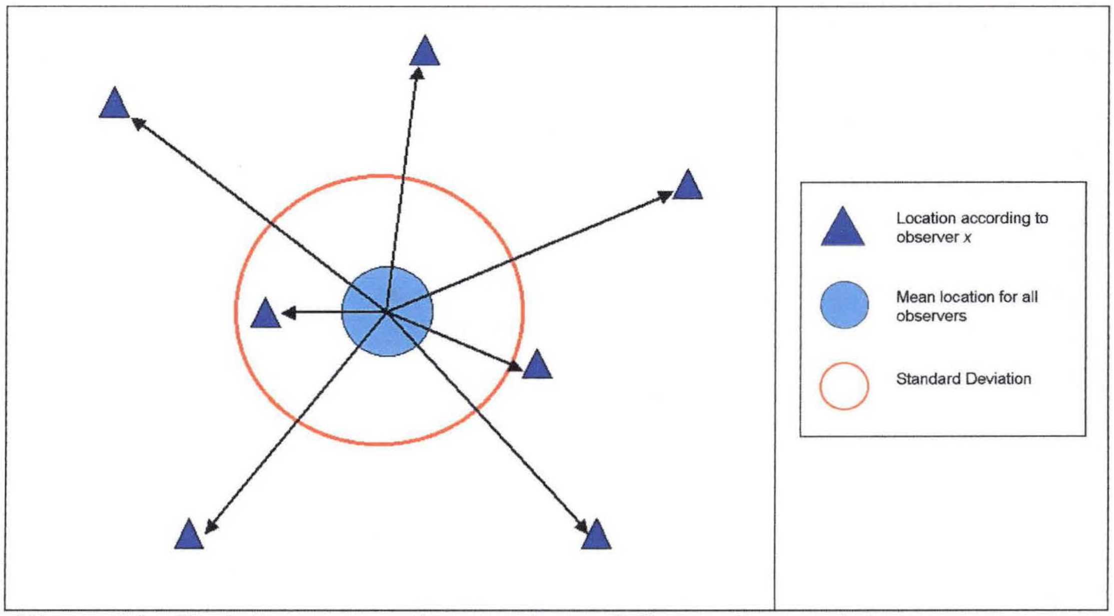


Figure 4-3: Variation among observers in spatially locating a point

4.3.1 Methodology

Eight different features with a sample size of 5 or 6 elements were randomly selected along Pilot Study Area 1. The features included signals, utility poles, drainage structures, medians, pedestrian crossings, intersection centers, railroad crossings, bridges, and driveways. Seven observers familiar with ArcView were selected to identify and locate each set of features in each dataset. A box was drawn around each element to provide a visual clue to guide the observer in finding the actual object as shown in Figure 4-4. This was done since the purpose of the study was to evaluate differences in where observers placed an object's location rather than whether or not an observer could actually locate the object in the imagery. Each observer was tested independently of the others to avoid bias.

Specific directions were provided as to how to locate a particular feature in order to avoid discrepancies. Observers were directed not to locate the center of the rectangle or circle drawn around each feature. For individual types of features, the following directions were provided:

1. Signal: Locate the central point where the signal post meets the ground. If the signal post has a concrete pedestal, locate the southeast corner of the pedestal.

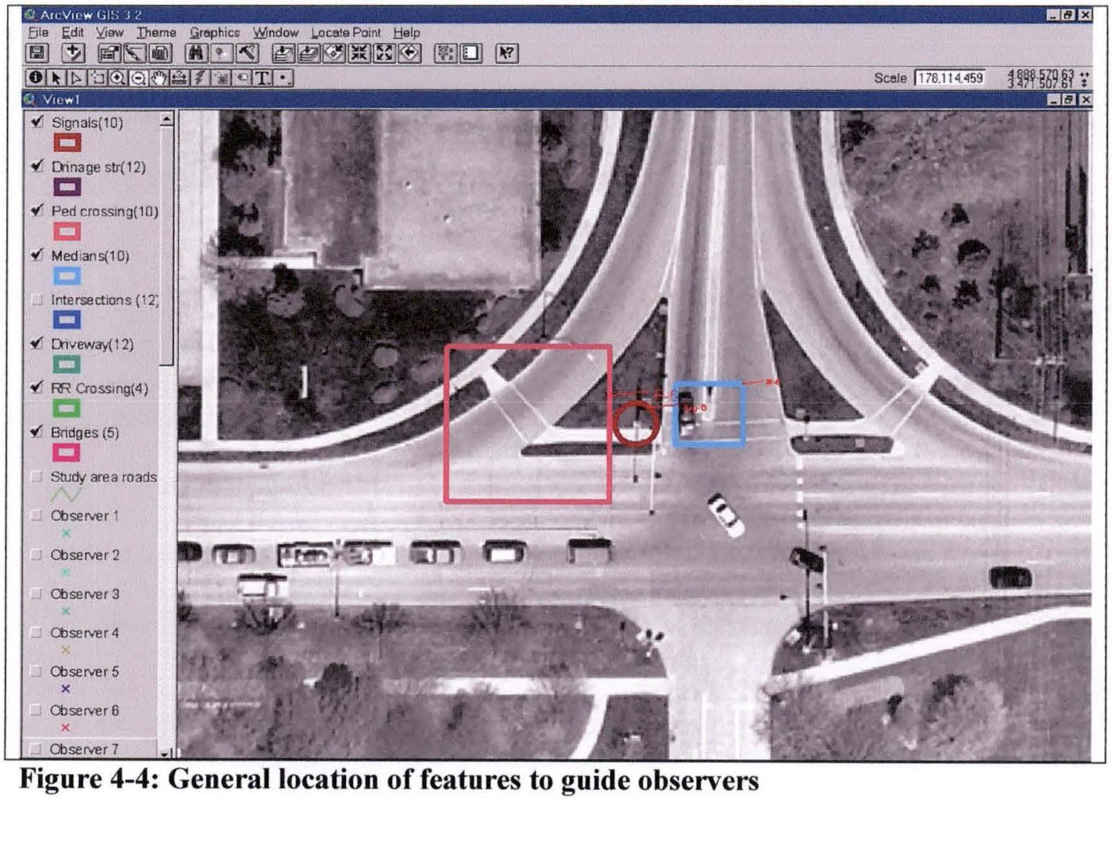


Figure 4-4: General location of features to guide observers

2. Utility Poles: Locate the central point where the pole meets the ground.
3. Drainage Structures: Locate the southeast corner of the drainage box.
4. Pedestrian Crossing: Locate the southeast corner of the pedestrian crossing.
5. Medians: Locate the tip of the semi-circular median.
6. Intersections: Locate the center of intersecting approaches.
7. Driveways: Locate the center of the driveway at the edge of roadway.
8. RR Crossings: Locate the center of the RR crossing and roadway approach.
9. Bridges: Locate the southeast corner of the bridge.

Observers located each feature using heads-up digitizing. ArcView Avenue scripts were developed to automatically update an attribute table with the coordinates of the location as digitized by the observer. Figure 4-5 illustrates the variation among the seven users in locating the southeast corner of a drainage box.

For the 2 and 6-inch datasets, all nine elements were included in the analysis. For the 24-inch and 1-meter datasets, only railroad crossings, intersections, and bridges were included. The other five features could not be consistently identified enough in the images to perform the analysis.

4.3.2 Results

Five or six items were tested for each feature. For example, the southeast corners of six drainage boxes were located by observers in each dataset. The mean and standard deviation for variation among observers for each feature were calculated with the results presented in Tables 4-3 to 4-10. As shown, the mean and standard deviation was less than or equal to 0.52 meters and 0.82 meters (1.7 feet, 2.7 feet) respectively for all of the five features that could only be identified in the 2 and 6-inch datasets (drainage structures, driveways, signal posts, medians, and pedestrian crossings). Railroad crossings were identified with a mean variation and standard deviation of less than or equal to 0.49 meters (1.6 feet) for the 2-inch, 6-inch, and 1-meter datasets. For the 24-inch dataset, the mean variation was 1.34 meters (4.4 feet) and the standard deviation was 1.10 meters (3.6 feet). For bridges, the mean variation and standard deviation was less than 1.49 meters (4.9 feet) for the 2-inch, 6-inch, and 1-meter datasets. For the 24-inch dataset, the mean and standard deviation were over 4.8 meters (15.7 feet), which is significantly higher than for the other datasets. For intersections, the mean variation and standard deviation were less than 1.34 meters (4.4 feet) for all datasets with a mean and standard deviation of less than 0.43 (1.4 feet) meters for the 1-meter.

It was expected that observer variation would increase as resolution decreased. However, for the three features common to all four datasets, the 1-meter dataset performed equally or better than the other datasets. This may be due to the fact that observers are more likely to "zoom" in on higher resolution images and may then lose sight of the object.

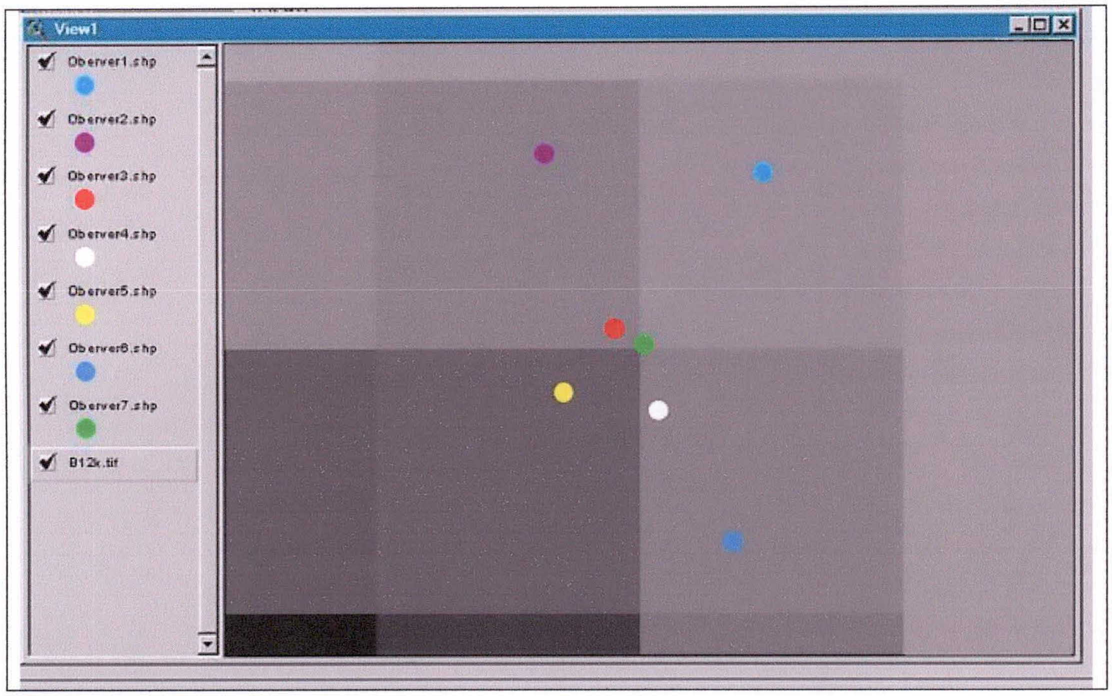


Figure 4-5: Edge of drainage structure as located by seven observers

Table 4-3: Drainage Structures

Dataset	Mean (meters)	Standard Deviation (meters)
2-inch	0.01	0.06
6-inch	0.09	0.24

Table 4-4: Driveways

Dataset	Mean (meters)	Standard Deviation (meters)
2-inch	0.43	0.30
6-inch	0.49	0.27

Table 4-5: Traffic Signal Posts

Dataset	Mean (meters)	Standard Deviation (meters)
2-inch	0.46	0.46
6-inch	0.46	0.46

Table 4-6: Medians

Dataset	Mean (meters)	Standard Deviation (meters)
2-inch	0.24	0.40
6-inch	0.52	0.82

Table 4-7: Pedestrian Crossings

Dataset	Mean (meter)	Standard Deviation (meter)
2-inch	0.34	0.40
6-inch	0.43	0.76

Table 4-8: Bridges

Dataset	Mean (meter)	Standard Deviation (meter)
2-inch	1.19	1.19
6-inch	1.46	1.31
24-inch	4.82	3.32
1-meter	1.49	1.04

Table 4-9: Intersections

Dataset	Mean (meters)	Standard Deviation (meters)
2-inch	1.34	0.82
6-inch	1.31	0.76
24-inch	1.28	0.88
1-meter	0.43	0.30

Table 4-10: Railroad Crossings

Dataset	Mean (meters)	Standard Deviation (meters)
2-inch	0.49	0.46
6-inch	0.21	0.15
24-inch	1.34	1.10
1-meter	0.37	0.24

4.3.3 Recommendations

Certain features, such as railroad crossings, could be located with less variation than features such as the center of an intersection or edge of a bridge for even lower resolution images. This is as would be expected since the center of a driveway is more difficult to establish precisely than the center of a signpost regardless of the image resolution. This indicates that if well-defined features can be identified for anchor points, only minor variation among observers are expected to occur. However, most features could not be identified in the lower resolution datasets, which limits their use for establishing the spatial location of anchor points. It also indicates that for features where it is difficult to establish an exact position, significant variations occur at all resolutions of imagery.

With higher resolution imagery, features that are distinct can be identified with little variation among users. As a result, the use of different observers to identify anchor points locations should not significantly affect positional accuracy for those features. More specific instructions as how to locate a feature may further reduce the amount of variation among observers.

When features did not have a distinct location for observers to identify (such as the center of an intersection), observers could not locate the feature to within the ± 1.0 m accuracy requirement for location of anchor points. This indicates that even with images with a high level of positional accuracy, certain features could not be located within the accuracy requirements for anchor points due only to observer error. Training may decrease observer variation and providing more specific instructions so that operators can consistently chose the same location.

5. USE OF IMAGERY AND VIDEO-LOGGING METHODS FOR CALCULATION OF ANCHOR SECTION LENGTHS

Final implementation of the Iowa DOT LRS project will require calculation of anchor section lengths for all roadways. Various methods to measure anchor section lengths, including high (6-inch) and low-resolution (24-inch) orthophotos were evaluated in the Iowa DOT LRS Pilot Study (GeoAnalytics, et al, 2001).

This research further explores the use of several methods to calculate anchor section lengths including use of imagery and two different video-logging methods. The 6-inch, 24-inch, and 1-meter datasets were used as a background for heads-up digitizing of the roadway centerline for test segments in Pilot Study Area 2. The 2-inch dataset was only available for one roadway in the pilot study area and was not included. Calculated distances were available from the Iowa DOT Pilot Study. A set of distances was also measured using by a vendor using a videolog DMI van.

5.1 Calculation of Anchor Section Lengths from Imagery

The centerline was digitized for each of the seven test segments for each of the three image datasets by first establishing BEGIN and END anchor points and then creating a centerline representation as described in the following sections. Heads-up digitizing was used to create anchor sections in ArcView 3.2. A centerline was created to provide a means of measuring length.

5.1.1 Anchor Points

For each of the seven test segments, a set of anchor points was located according to the business rules established for the Iowa DOT LRS (GeoAnalytics et al., March 2001). They marked the BEGIN and END points for anchor sections (FROM/TO). Specific descriptions of the BEGIN and END points for each segment were obtained from the Iowa DOT Pilot Study and are provided in Appendix B. In most cases anchor points were located at the center of an intersection. The center of the intersection was defined as the point where the centerline of each approach met.

5.1.2 Anchor Sections

Anchor sections were created using the following protocol:

1) The "FROM" anchor point established the beginning of the segment;
2) The roadway centerline was determined by the following method:
    a. A series of lines were drawn along the length of the segment from one edge of the roadway to the other perpendicular to the centerline, significant changes in cartography were characterized by more lines (see Figure 5-1);
    b. An ArcView Avenue script was created to calculate the center of each line and place a point at the center of the roadway (see Figure 5-2). This established the roadway centerpoint (1/2 way mark) not the centerline of

the roadway as marked by pavement markings, which may not reflect the road center if road configurations such as 2-lanes in one direction and 1-lane in the other are present.

3) The "TO" anchor point was established according to the business rules for the Iowa DOT LRS;

4) An Avenue script was written by Mr. Michael Pawlovich of the Iowa DOT to create a polyline from the set of center and anchor points (see Figure 5-3);

5) Segment length was calculated using an Avenue script.

5.2 Calculation of Anchor Section Lengths Using Video-Logging

A Videolog Van DMI was used for the test segments included in the Iowa DOT pilot study. The van usually drove each segment in each direction for bi-directional roadways producing two DMI measurements with a corresponding GPS trace for each section tested (GeoAnalytics, et al, 2001).

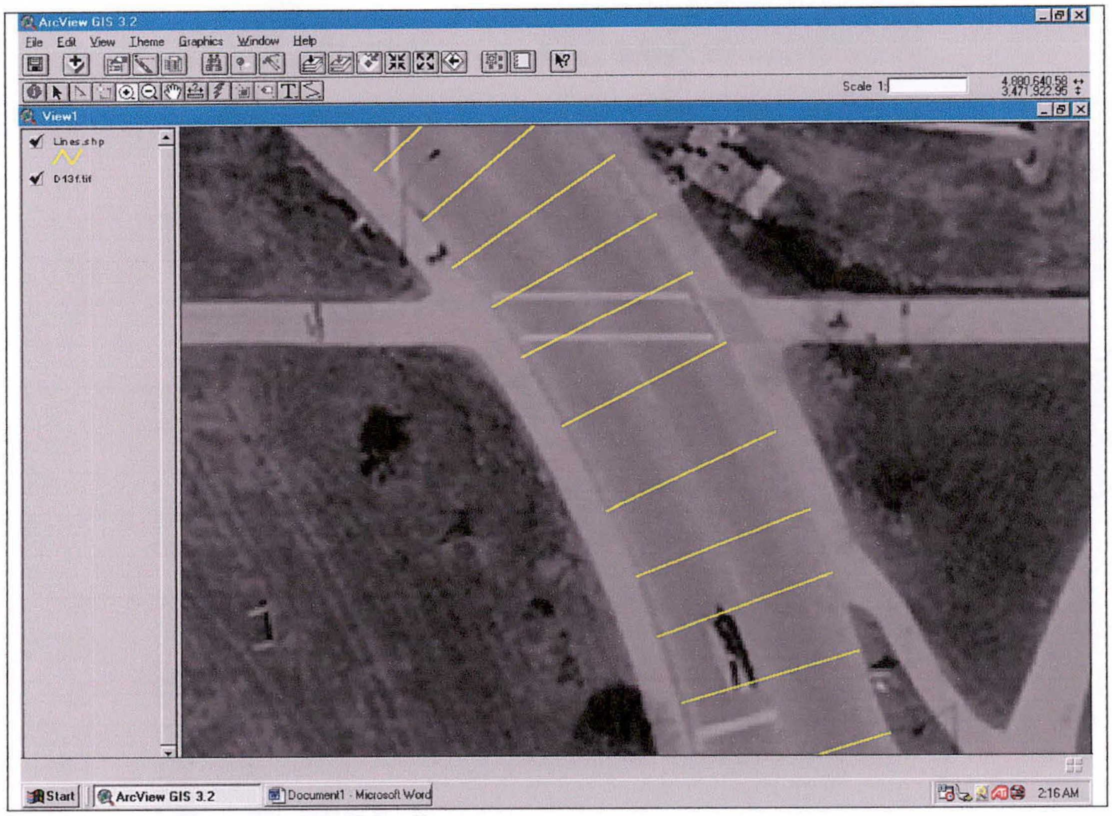


Figure 5-1: Determining Edgelines

Figure 5-2: Centerline Determination

Figure 5-3: Calculation of Roadway Centerline

An independent videolog vendor agreed to collect segment lengths for several of the test segments. The vendor was collecting pavement condition data in the vicinity of the study area and agreed to complete some testing for the research team. Their videolog van also used DMI and DGPS technology and was used to measure segment length. The operators initially agreed to measure the eight test segments included in Pilot Study 2. However, Grand Avenue was under construction at the time that data collection occurred. Independent videolog data could also not be collected for the Dartmoor and Thackery segments for technical reasons. Although it was intended for the data to be collected at smaller intervals, the van ended up only collecting data to ± 10 meters. Data can be collected at finer intervals but once data were collected for this project, it could not be recollected. Consequently, results are likely to be coarser than expected.

5.3 Methodology and Results

The segment lengths collected using by the Iowa DOT for the LRS pilot study were used as the baseline against which the other methods were compared. Two Videolog measurements were usually available for each test segment since the van was typically driven in both directions. The two readings were averaged to give a final length for each segment. The difference between Videolog measurements and those of the other methods were calculated as well as the mean difference, standard deviation, and RMS. The calculated differences between each method and the Videolog measurements are given in Table 5-1. Mean, standard deviation, and RMS are provided in Table 5-2.

Large differences between the Videolog measurements and all other data collection methods were recorded for the Grand segment. Differences from –81 (6-inch imagery dataset) to –59 meters resulted (-193.6 to 265.7 feet). The segment was reexamined to determine possible problems, but the only potential reason for the large discrepancy was that the anchor point at the south end of the segment was located at a median, which may have been located differently using the Videolog van than the other methods for some reason. It was decided that the discrepancy was so large that it should be attributed to something other than how accurately the different methods were able to measure a segment and was subsequently dropped from further calculations (mean, std, RMS).

None of the evaluated methods meet the Iowa DOT LRS accuracy requirements of ± 2.1 meters for anchor section distances. For the 24-inch imagery dataset, a mean of 1.25 meter, a standard deviation of 5.61 meters, and an RMS of 5.35 meters resulted (4.1, 18.4, and 17.6 feet). The Iowa DOT LRS Pilot Study found similar results for low-resolution orthophotos (24-inch pixel). They reported a mean of –1.5 meters, standard deviation of 3.5 meters, and an RMS of 3.8 meters when compared against the Iowa DOT pilot study Videolog Van DMI data (-4.9, 11.5, and 12.5 feet). The results from this research were however based on a much smaller sample size.

For high-resolution orthophotos (6-inch pixels), the Iowa DOT LRS Pilot Project reported significantly better results than were found in this study. The DOT pilot study reported a mean of –1.3 meters, a standard deviation of 1.8 meters, and an RMS of 2.2 meters when compared against the Iowa DOT pilot study videolog van DMI data (-4.3, 5.9, and 7.2 feet). In contrast, this study found a mean of 0.98 meters, a standard deviation of 5.36 meters, and an RMS of 5.05 meters (3.2, 17.6, and 16.6 feet). However, the DOT pilot study for high-resolution orthophotos was also based on a significantly larger sample size. Additionally, the DOT pilot study used an iterative methodology that rejected test segments when the differences between the baseline DMI distances and those for data collection method were greater than some threshold value. This method was not applied to the results of this study.

Differences between the digitized anchor section distances and the calculated Iowa DOT pilot study VideoLog DMI differences may be attributed to how well the anchor points that were selected in the imagery corresponded to selection of anchor points in the field as well as accuracy of the photos themselves.

The mean difference between the Iowa DOT pilot study Videolog DMI and the independent videolog/DMI measurements was –10.58 meters (-34.7 feet) with a standard deviation of 9.08 meters (29.8 feet) and an RMS of 13.18 meters (43.2 feet). These measurements however were based on a sample size of 4 segments once the Duff Avenue segment was discarded. The Iowa DOT Pilot study also evaluated an independent videolog/DMI van but only tested three segments. The only results from the Iowa DOT study were that a difference of –137 meters (450 feet) existed for one segment. This measurement was significantly worse than for the independent videolog van segment used in this study. For the four test sections, differences between the independent vidoelog measurements and the Iowa DOT pilot study videolog DMI measurements ranged between 4.15 to 23.65 meters (13.6 to 77.6 feet).

The major potential problem with the use of remotely sensed imagery to create anchor sections is that aerial photographs only offer a planar view of the ground surface. Consequently, significant changes in vertical roadway profile cannot be accounted for. Only DMI measurements are capable of recoding changes in vertical alignment. Several of the test segments were characterized by large changes in vertical alignment (particularly State, Dakota, and Grand). However, results for these segments were similar to results for segments with flatter vertical profiles.

Table 5-1: Difference Between Anchor Section Length and Videolog Length (meters)

Segment	6-inch	24-inch	1 meter	Vendor provided Videolog/DMI data
Dartmoor	-1.89	-0.09	-1.10	
Dakota	7.47	8.81	16.43	23.65
Duff	-80.96	-77.24	-78.52	-58.49
Grand	-4.48	-6.28	-3.17	
State	0.40	4.33	-1.89	9.75
Thackery	2.87	-2.90	0.79	
Todd	7.83	7.13	7.13	4.15
Union	-5.43	-2.29	-4.42	4.75

Table 5-2: Comparison of Differences Between Data Collection Methods and Videologging Measurements for Anchor sections without Duff Avenue in the Calculations

Method	Mean (meters)	Standard Deviation (meters)	RMS (meters)	Sample Size
Vendor provided Videolog/DMI data	-10.58	9.08	13.18	4
6-inch Imagery	0.98	5.36	5.05	7
24-inch Imagery	1.25	5.61	5.35	7
1-meter Imagery	1.95	7.41	7.13	7

6. USE OF IMAGERY FOR CREATION OF A SPATIAL REPRESENTATION OF THE LRS DATUM

The main requirements of the Iowa DOT LRS are that the selected data collection method meets the accuracy requirements for both anchor point locations and anchor section distances. The datum, created as part of system implementation, will consist of spatially located anchor points and distance measurements between anchor points. Ideally the data collection method employed will also produce a cartographic by-product that can be used as a more accurate centerline representation than the current GIMS cartography.

The Videolog van tested by the DOT as well as the vendor provided independent DGPS data. DGPS were used to created spatial representations of the segments measures. Additionally all imagery datasets evaluated in this research are all capable of producing a spatial representation of the LRS datum. This section discusses and compares the use of the different methods for creating such a product.

Section 5 discussed the calculation of anchor section lengths for eight test segments in Pilot Study 2. In order to measure the anchor section distance between anchor points for each of the three imagery datasets (6-inch, 24-inch, and 1-meter), spatial representations of the centerlines of each segment were created. Although the Iowa DOT pilot study videolog/DMI and independent vendor videolog/DMI vans used DMI to calculate anchor section distances, both methods also produced a string of DGPS coordinates that represented the data collection van's position along the test segment. As a result, spatial representations of the roadway were available for evaluation.

6.1 Reference Baseline

The centerline representation created using the 6-inch imagery dataset was selected as a baseline against which other spatial representations were compared. Although the six-inch dataset did not meet the linear accuracy requirements for anchor section distances, it was decided that it still would produce the best cartographic representation of the centerline. The images were of high enough resolution that the edge of roadway could clearly be identified and distinguished from adjacent material, such as shoulders, etc. Pavement markings and medians could readily be identified. This allowed the center of the roadway to be established fairly easily.

6.2 Methodology for Comparison of Centerline Representations

The cartography created using imagery for the 24-inch dataset and 1-meter dataset and DGPS for the Iowa DOT pilot study and vendor datasets were compared against the 6-inch centerline for each of the eight segments (except for the vendor dataset which only had 5 segments). Differences between the datasets were evaluated by calculating the deviation between the dataset under consideration and the 6-inch baseline. An ArcView

Avenue script measured the distances between the two segments under consideration using the following:

1) Identify the BEGIN point for each segment and measure the distance between the two;
2) Walk along each segment at 1% intervals and establish a point;
3) Calculate the distance between the two segments at each 1% interval;
4) Report the results to a database.

The 24-inch and 1-meter dataset cartography represented the center of the roadway and therefore was directly comparable to the 6-inch baseline. Significant random deviations from the baseline would indicate that the centerline did not adequately represent the horizontal alignment of the segment being tested. The cartography created using the Iowa DOT pilot study videolog or vendor videolog van represented the center of the lane in which the van was traveling when data were collected. As a result, those cartographic representations should have been offset from the baseline at a consistent interval. Deviations about that offset interval would also indicate inaccurate characterizations of the roadway horizontal alignment. This concept is illustrated in Figure 6-1. However, this comparison is qualitative and is not directly comparable to the centerline representations created for the imagery datasets.

Results are provided in the sections below for each of the eight test segments. The average deviation was calculated as well as the minimum and maximum distances. In most cases, each Iowa DOT pilot study videolog and independent vendor videolog "run" produced two cartographic byproducts, one for each direction.

6.2.1 Dakota

The test corridor along Dakota was a fairly straight segment in terms of horizontal alignment. Some changes in vertical alignment were present. Results for the Dakota test segment are provided in Table 6-1 and Figures 6-2 to 6-4. As shown, the 24-inch dataset performed the best with an average deviation of less than 0.3 meters (1.0 feet). The 24-inch centerline only deviated 1.1 meters (3.6 feet) from the baseline at most along the entire length of the segment. Only one Iowa DOT pilot study DGPS segment was available. Both DGPS methods from the videolog vans performed the most poorly. For the Iowa DOT pilot study DGPS data, the average deviation was only 2.07 meters (6.8 feet), which may have indicated an offset of two meters from the baseline centerline due to the van's position during data collection. However, the deviation from the baseline varied widely along the length of the segment from 0.03 to 7.41 meters (0.1 to 24.3 feet).

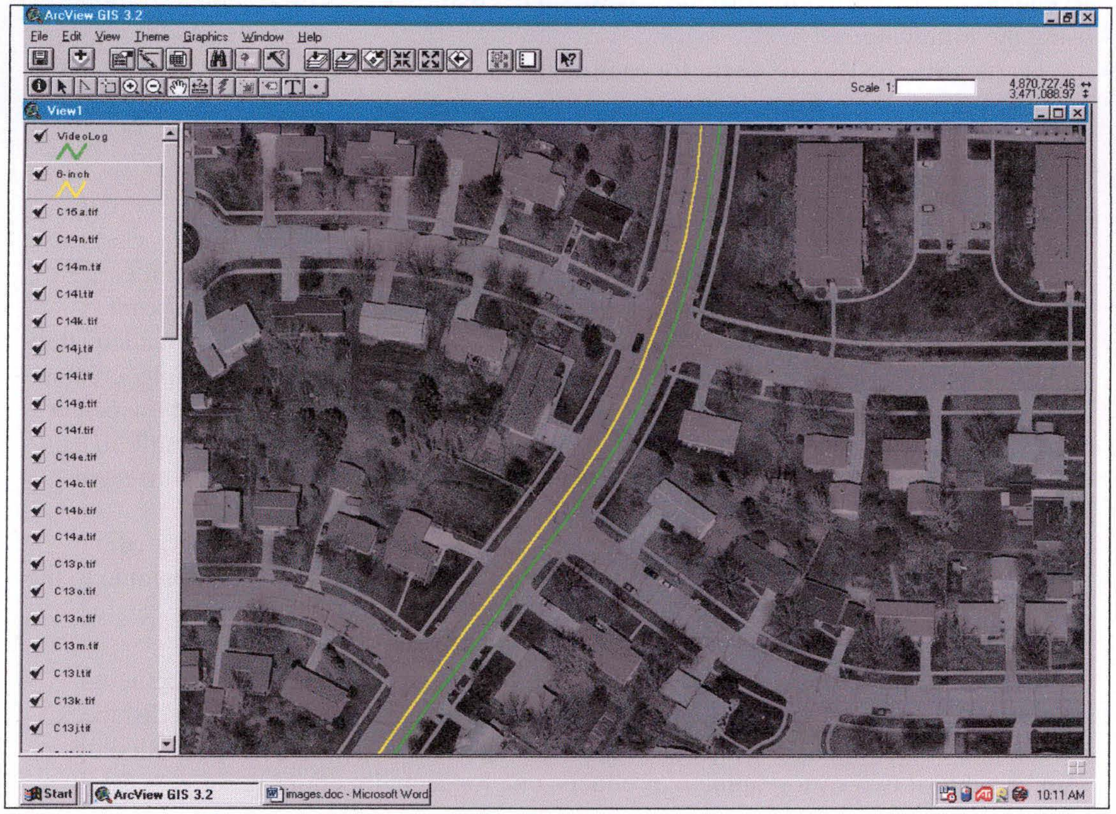


Figure 6-1: Videolog GPS Trace Offset From Centerline

Table 6-1: Results for the Dakota Test Segment

	Dataset				
	24-Inch	1-Meter	Vendor DGPS 1	Vendor DGPS 2	DOT Pilot Study DGPS 1
Mean Deviation (meters)	0.27	1.74	3.47	3.87	2.07
Minimum Deviation (meters)	0.0	0.06	0.40	2.10	0.03
Maximum Deviation (meters)	1.10	3.90	7.56	8.29	7.41

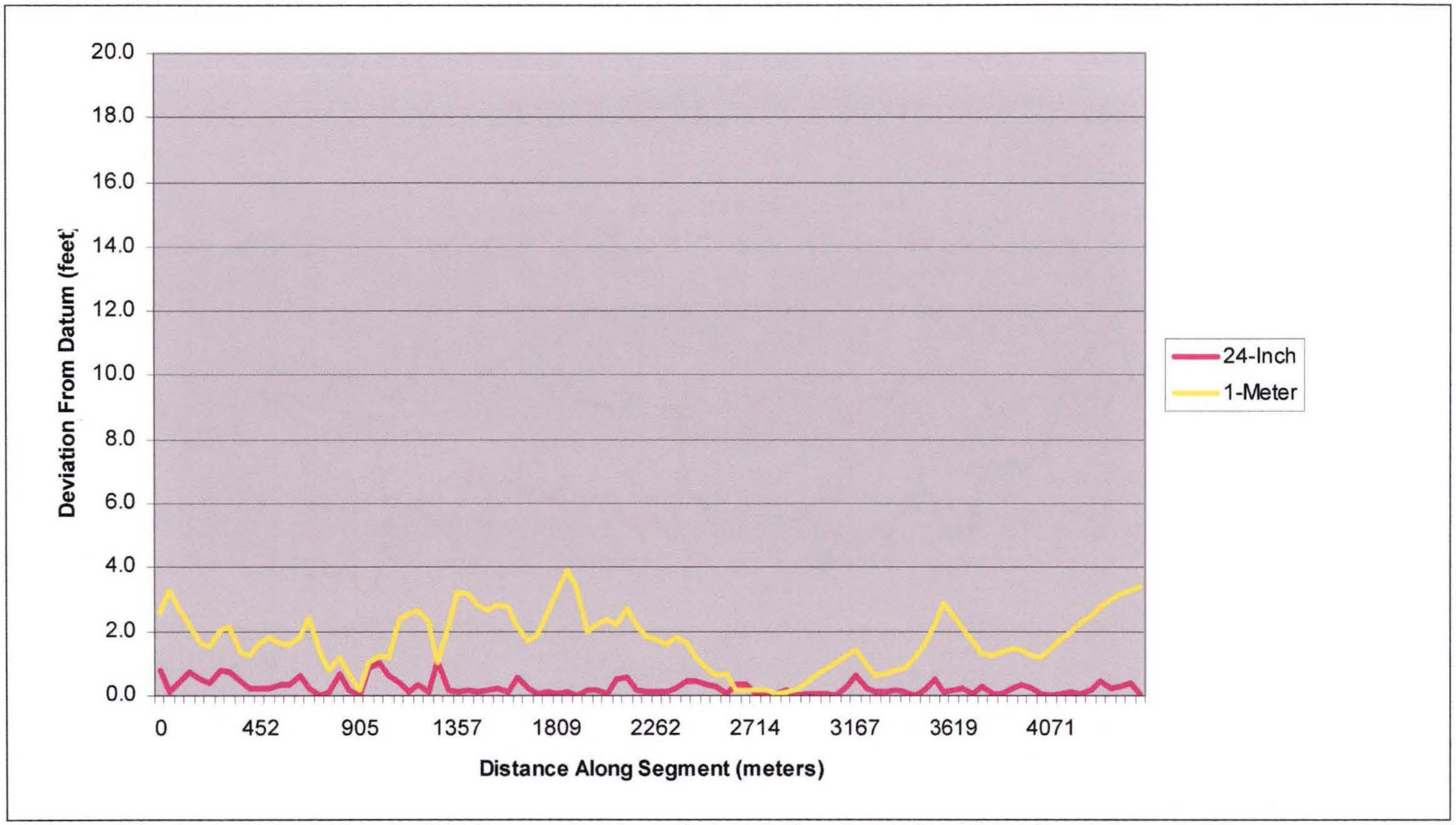


Figure 6-2: Plot of Deviation by 1% Intervals Along Segment for the Dakota Test Segment

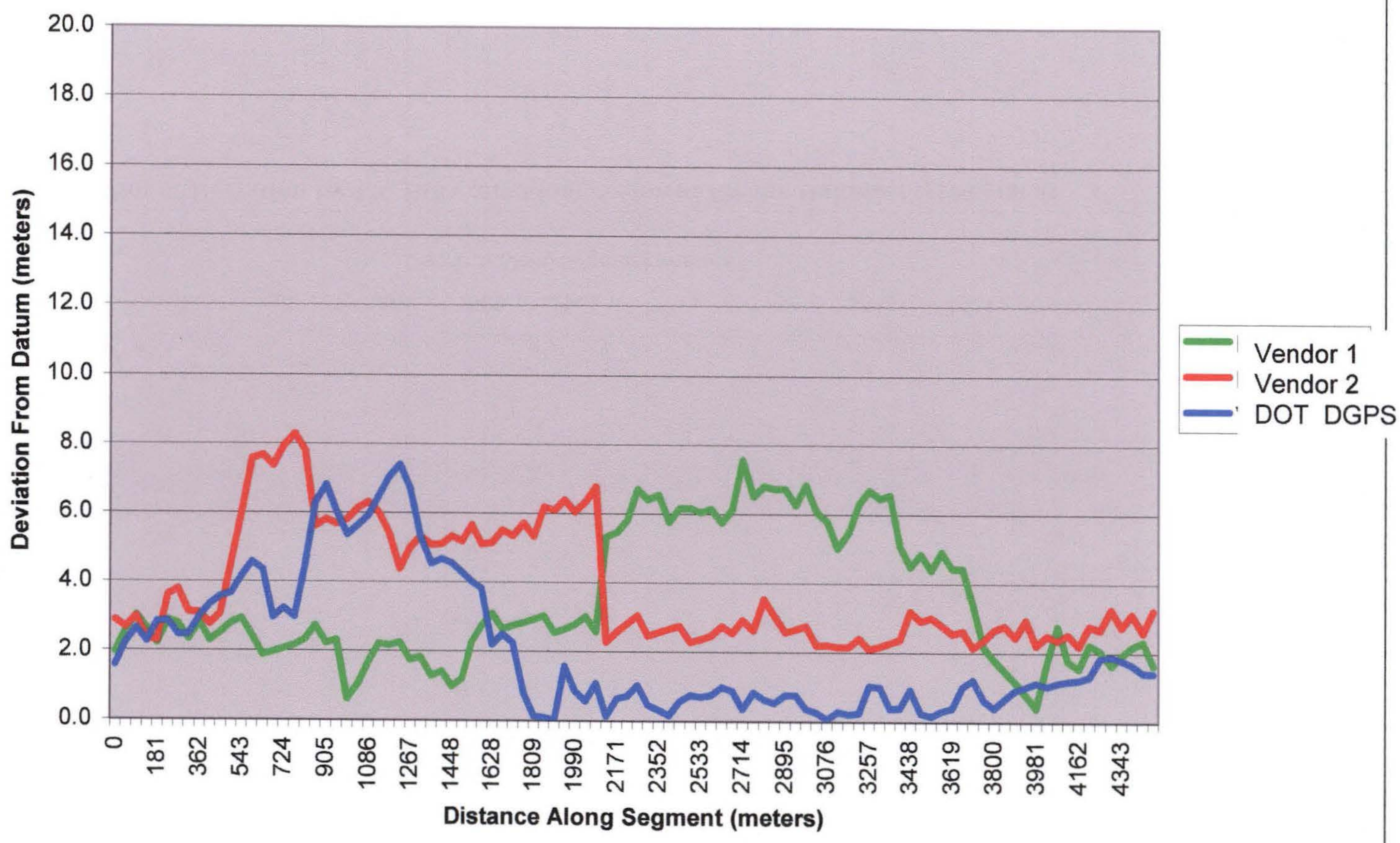


Figure 6-3: Plot of Deviation by 1% Intervals Along Segment for the Dakota Test Segment (cont.)

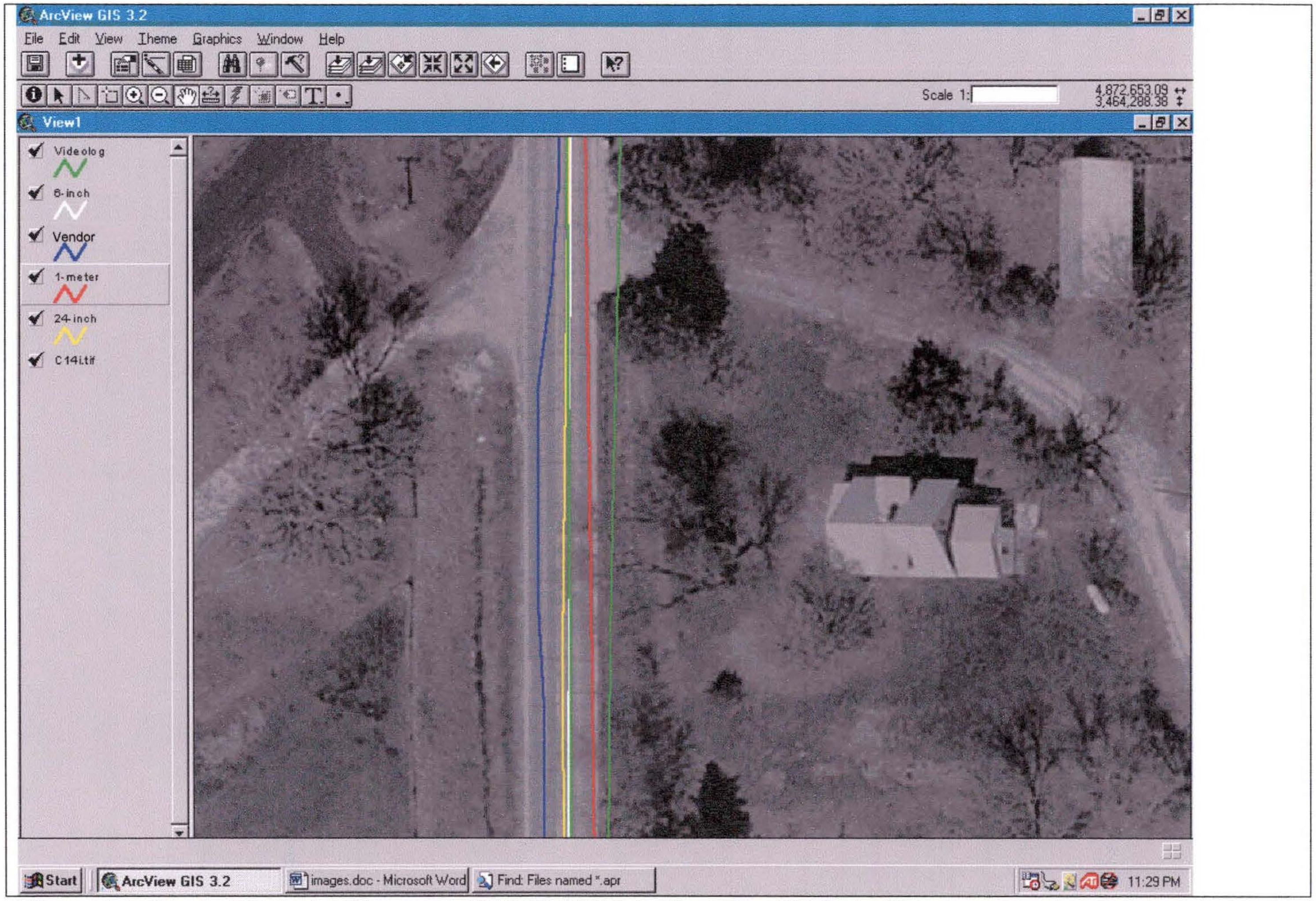


Figure 6-4: Typical Dakota Alignment (DOT DGPS is indicated as "Videolog")

6.2.2 Dartmoor

Results for the Dartmoor segment are shown in Table 6-2 and Figures 6-5 to 6-7. Dartmoor did have several changes in horizontal alignment. However, the most significant deviation from the baseline was only 5.12 meters (16.8 feet) for one of the Iowa DOT pilot study DGPS segments (mean deviation was 2.61 meters {8.6 feet}). The mean deviation for the 24-inch and 1-meter imagery datasets was 0.33 and 1.13 meters (1.1 and 8.6 feet), respectively. The mean deviation for the second Iowa DOT pilot study DGPS segment was only 1.53 meters (5.0 feet). No vendor DGPS data were available for Dartmoor. Figure 6-7 illustrates the "worst" location along Dartmoor in terms of deviation from the centerline.

Table 6-2: Results for the Dartmoor Test Segment

	Dataset			
	24-Inch	**1-Meter**	**DOT pilot study DGPS 1**	**DOT pilot study DGPS 2**
Mean Deviation (meters)	0.33	1.13	2.61	1.53
Minimum Deviation (meters)	0.0	0.0	0.09	0.0
Maximum Deviation (meters)	1.31	3.87	5.12	4.75

6.2.3 Duff Avenue

The Duff Avenue corridor was characterized by very little horizontal curvature or vertical curvature or grades. The 24-inch and 1-meter segments showed the most deviation as shown in Figures 6-8 and 6-10. The mean deviation for the 1-meter was 4.52 meters (14.8 feet) with a standard deviation of 0.82 meters (2.7 feet) and a maximum deviation of 7.56 meters (24.8 feet). The vendor DGPS and Iowa DOT pilot study DGPS segments demonstrated the least deviation about the mean. Average, minimum, and maximum deviation from the baseline are given in Table 6-3.

Table: 6-3 Results for the Duff Test Segment

	Dataset					
	24-Inch	1-Meter	Vendor DGPS 1	Vendor DGPS 2	DOT pilot study DGPS 1	DOT pilot study DGPS 2
Mean Deviation (meters)	1.85	4.62	8.49	7.32	0.80	8.24
Minimum Deviation (meters)	0.15	0.82	6.22	5.61	0	6.16
Maximum Deviation (meters)	5.61	7.56	10.36	8.63	8.50	10.39

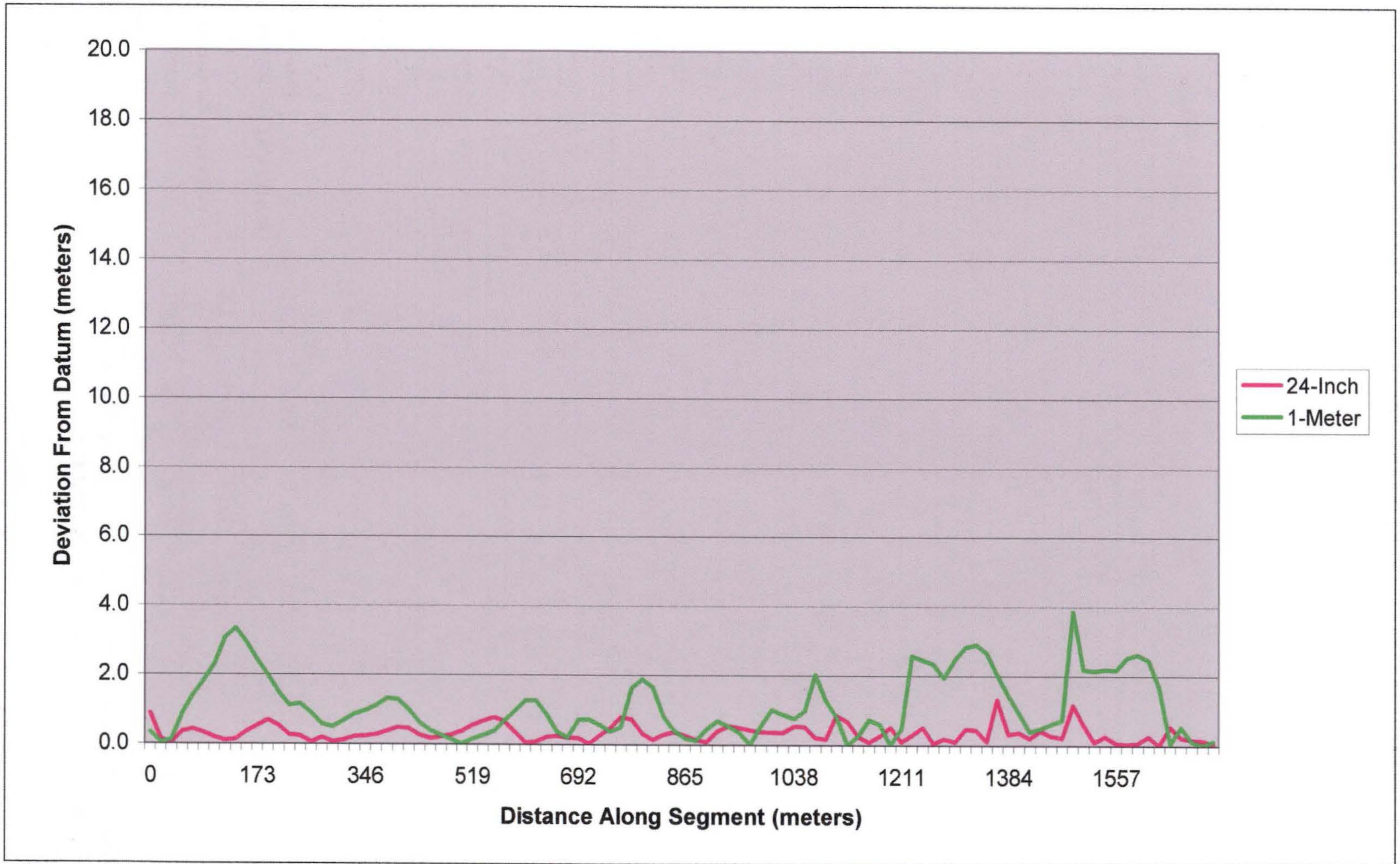


Figure 6-5: Plot of Deviation by 1% Intervals Along Segment for the Dartmoor Test Segment

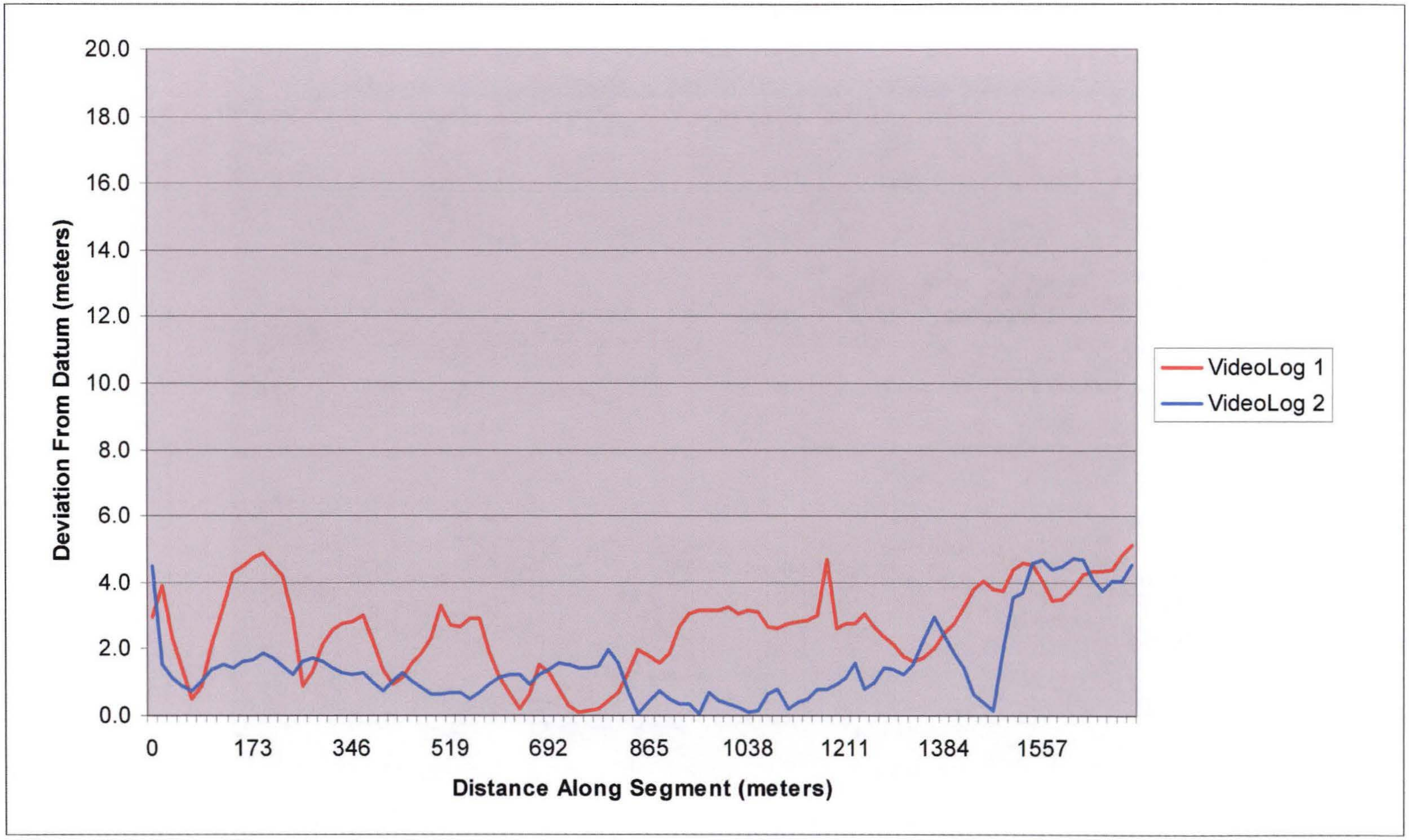


Figure 6-6: Plot of Deviation by 1% Intervals Along Segment for the Dartmoor Test Segment (Videolog 1 and 2 indicates the Iowa DOT Pilot Study DGPS)

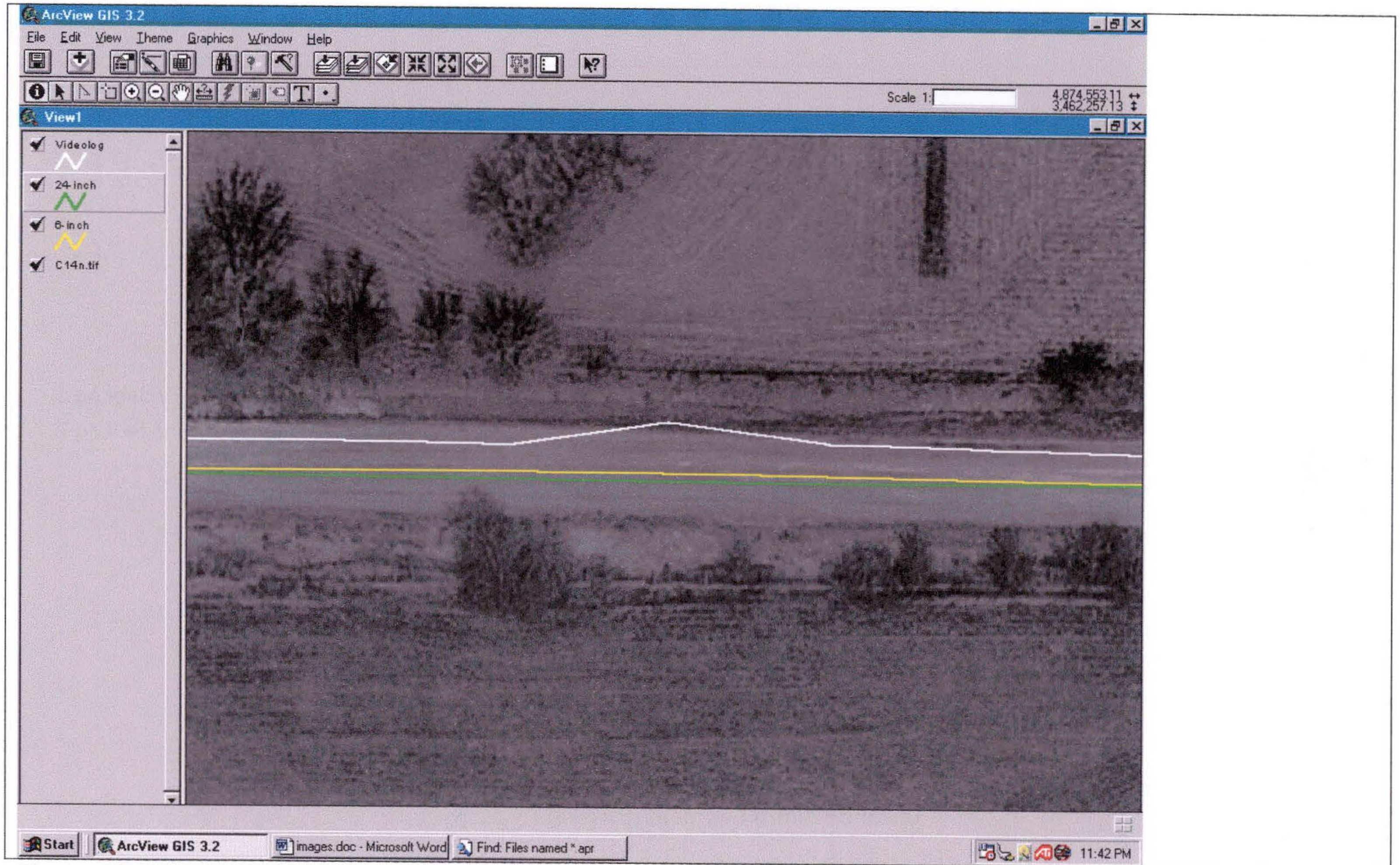


Figure 6-7: Worst Case Dartmoor Alignment with Maximum Deviation of 5.81 meters (Videolog indicates the Iowa DOT Pilot Study DGPS)

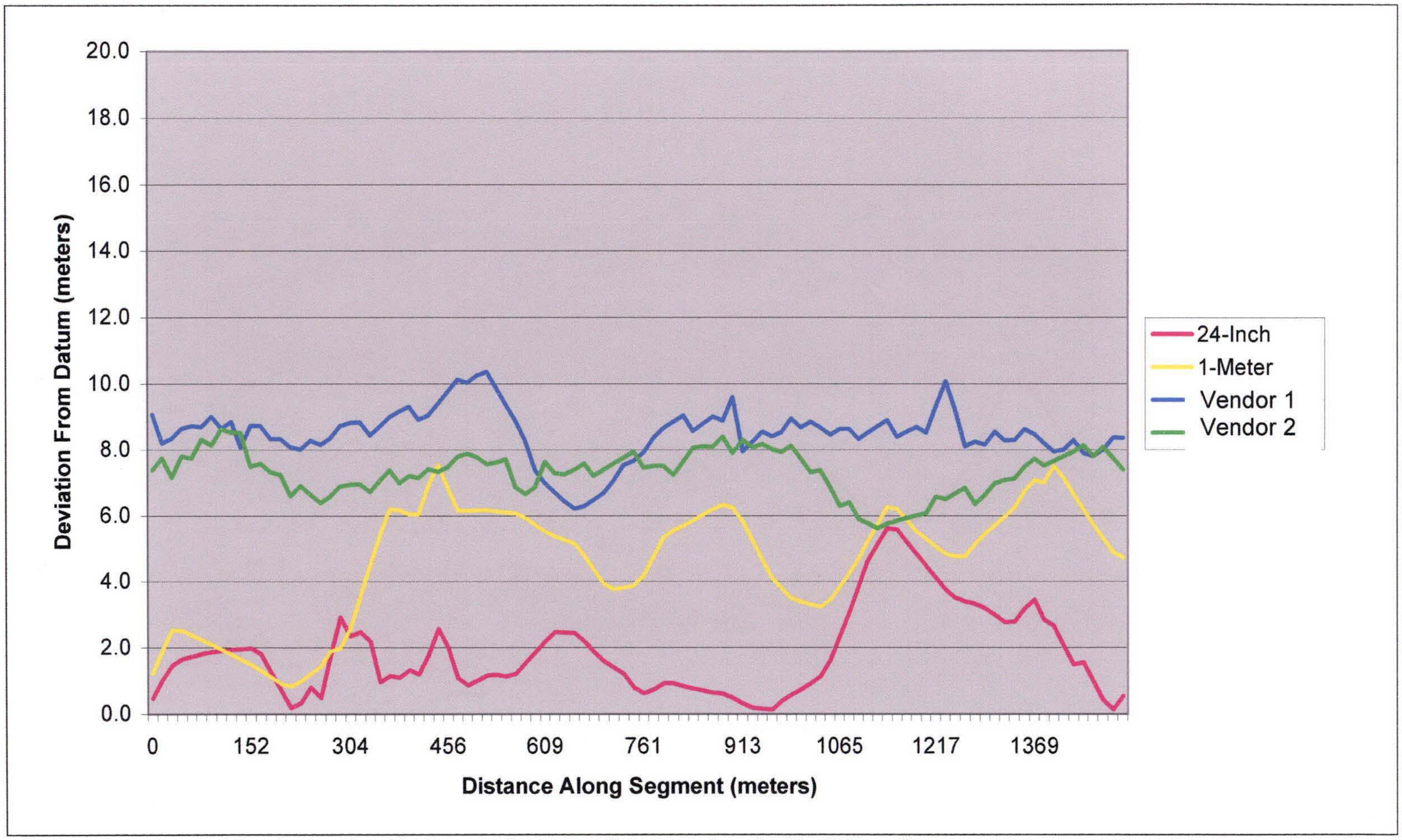


Figure 6-8: Plot of Deviation by 1% Intervals Along Segment for the Duff Test Segment

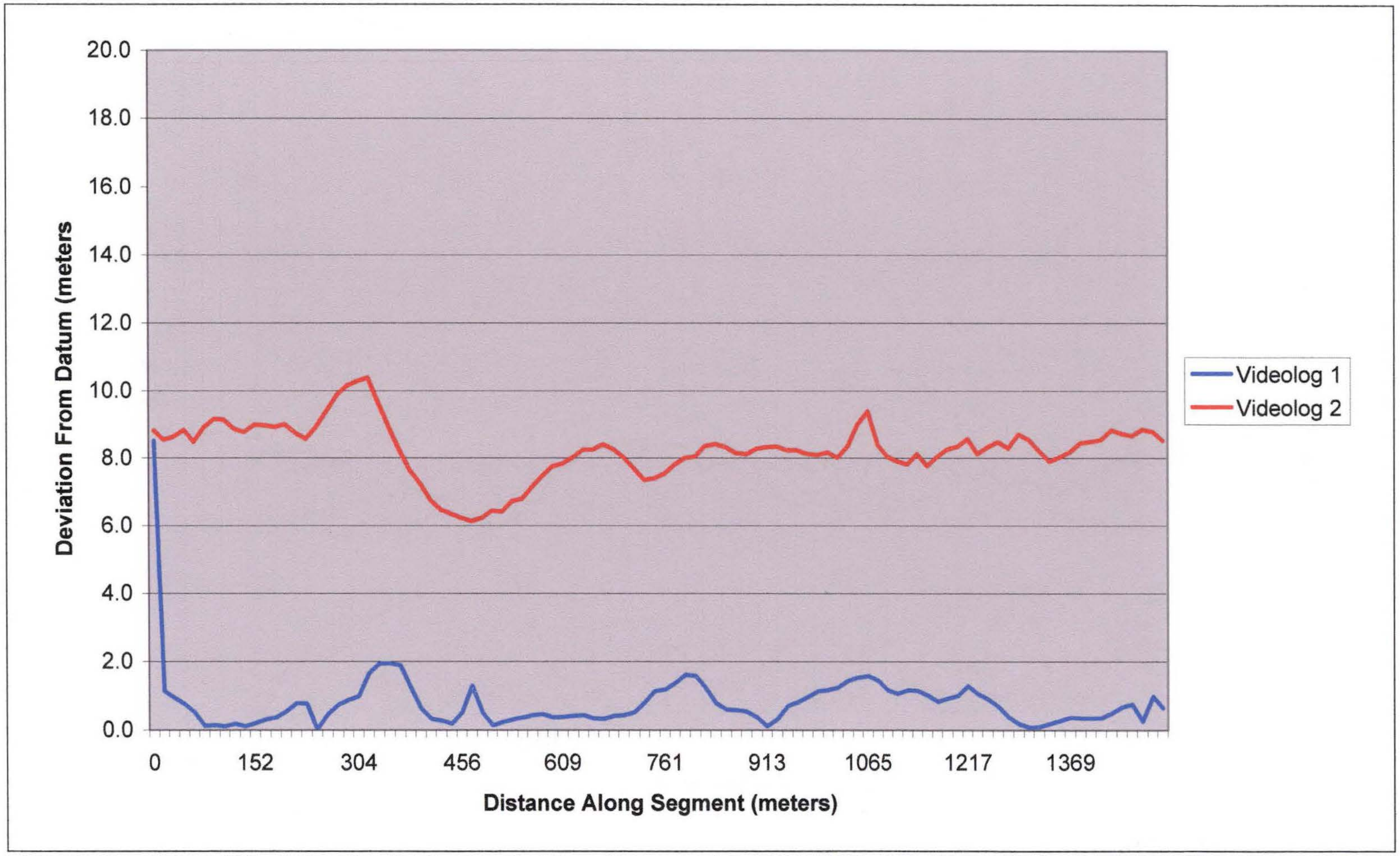


Figure 6-9: Plot of Deviation by 1% Intervals Along Segment for the Duff Test Segment (Videolog 1 and 2 indicates the Iowa DOT Pilot Study DGPS)

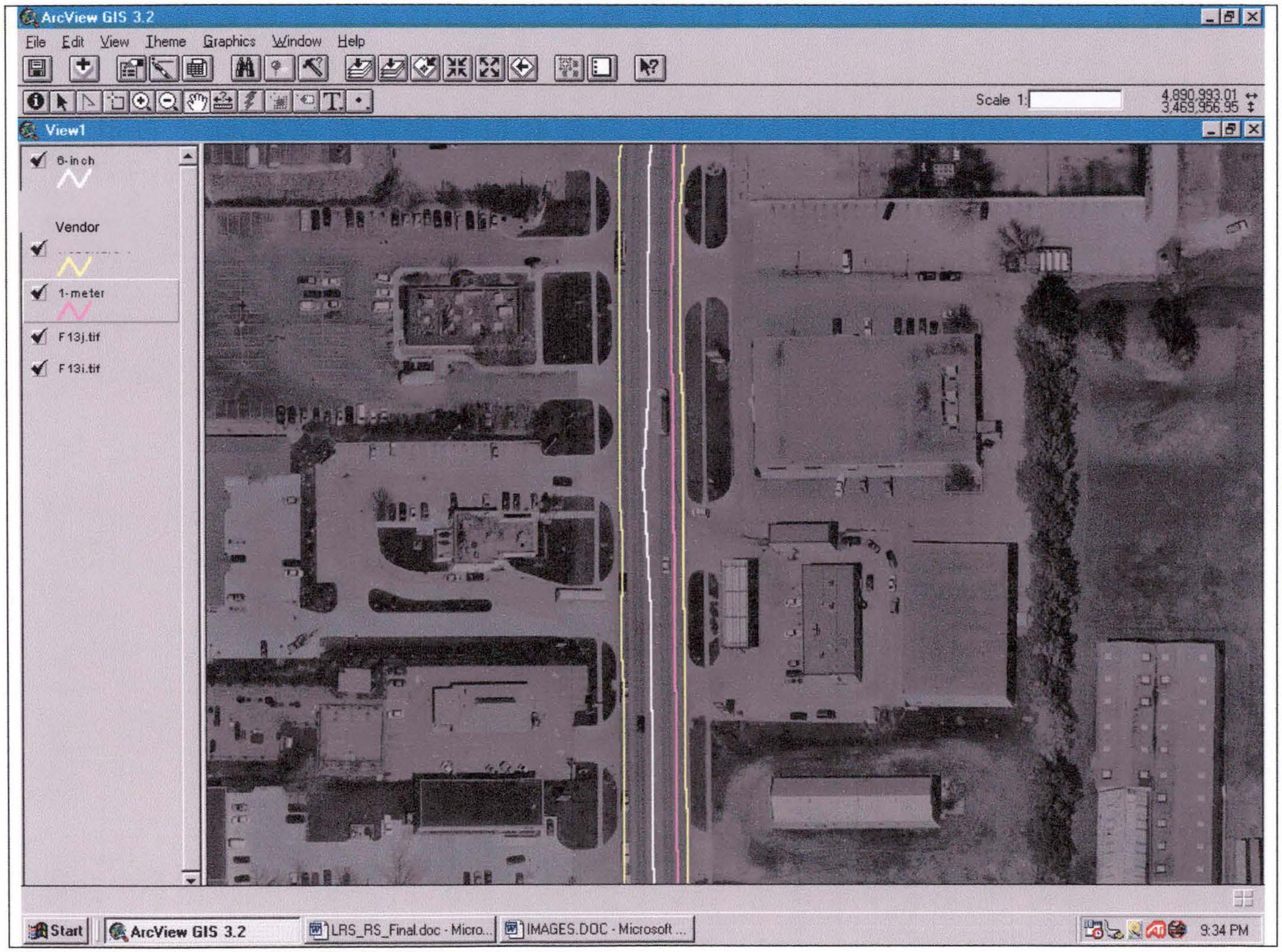


Figure 6-10: Worst Case Duff Alignment

6.2.4 Grand Avenue

The Grand Avenue Corridor was also characterized by little horizontal curvature. Significant vertical changes in alignment were present. Grand Avenue was closed for construction at the time the vendor DGPS segments were collected, so vendor DGPS information was available. The first Iowa DOT pilot study DGPS segment deviated from the baseline an average of 5.16 meters (16.9 feet), but was only 0.03 meters (0.1 feet) away from the baseline at the closest point. The maximum deviation was 15.30 meters (50.2 feet) as shown in Table 6-4. Segments from the imagery datasets had the least deviation as shown in Table 6-4 with a mean deviation of less than one meter (3.5 feet) for the 24-inch dataset and less than 3 meters (10 feet) for the 1-meter dataset. A plot of deviation along the length of the segment for the different methods is provided in Figure 6-11. The worst alignment is shown in Figure 6-12.

Table 6-4: Results for the Grand Test Segment

	Dataset			
	24-Inch	1-Meter	DOT Pilot Study DGPS 1	DOT Pilot Study DGPS 2
Mean Deviation (m)	0.85	2.76	5.16	5.96
Minimum Deviation (m)	0.0	0.0	0.03	4.61
Maximum Deviation (m)	2.01	5.12	15.30	8.35

6.2.5 State Street

The State Street Corridor was characterized by horizontal curvature as well as significant changes in vertical alignment. Three DGPS segments were available for the State Street Corridor from the Iowa DOT pilot study. Mean, maximum, and minimum deviations from the 6-inch baseline are given in Table 6-5. As shown in Figures 6-13 and 6-15, for all but the third DGPS segment, deviation around the mean was usually less than 4 meters (13 feet). The third DGPS segment deviated significantly from the baseline in several locations as shown. The mean deviation was 3.72 meters (12.2 feet) with the maximum deviation at 17.16 meters (56.3 feet).

Table 6-5: Results for the State Test Segment

	Dataset						
	24-Inch	1-Meter	Vendor DGPS 1	Vendor DGPS 2	DOT Pilot Study DGPS 1	DOT Pilot Study DGPS 2	DOT Pilot Study DGPS 3
Mean Deviation (m)	0.80	1.82	2.35	2.26	2.01	5.44	3.72
Minimum Deviation (m)	0.0	0.30	1.01	1.25	0.0	2.26	0.03
Maximum Deviation (m)	3.26	4.79	3.54	3.26	4.91	7.77	17.16

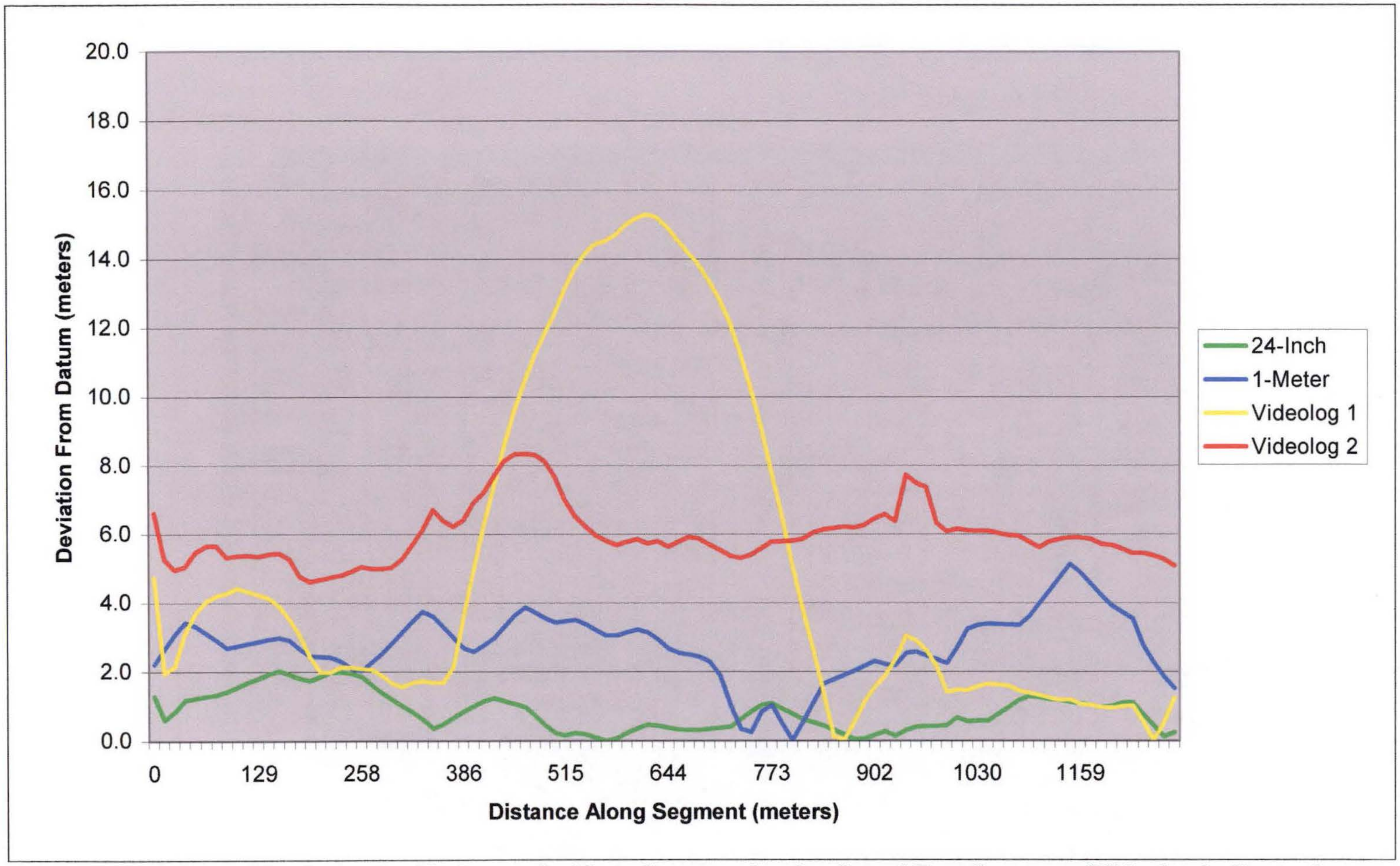


Figure 6-11: Plot of Deviation by 1% Intervals Along Segment for the Grand Test Segment (Videolog indicates Iowa DOT DGPS Segments)

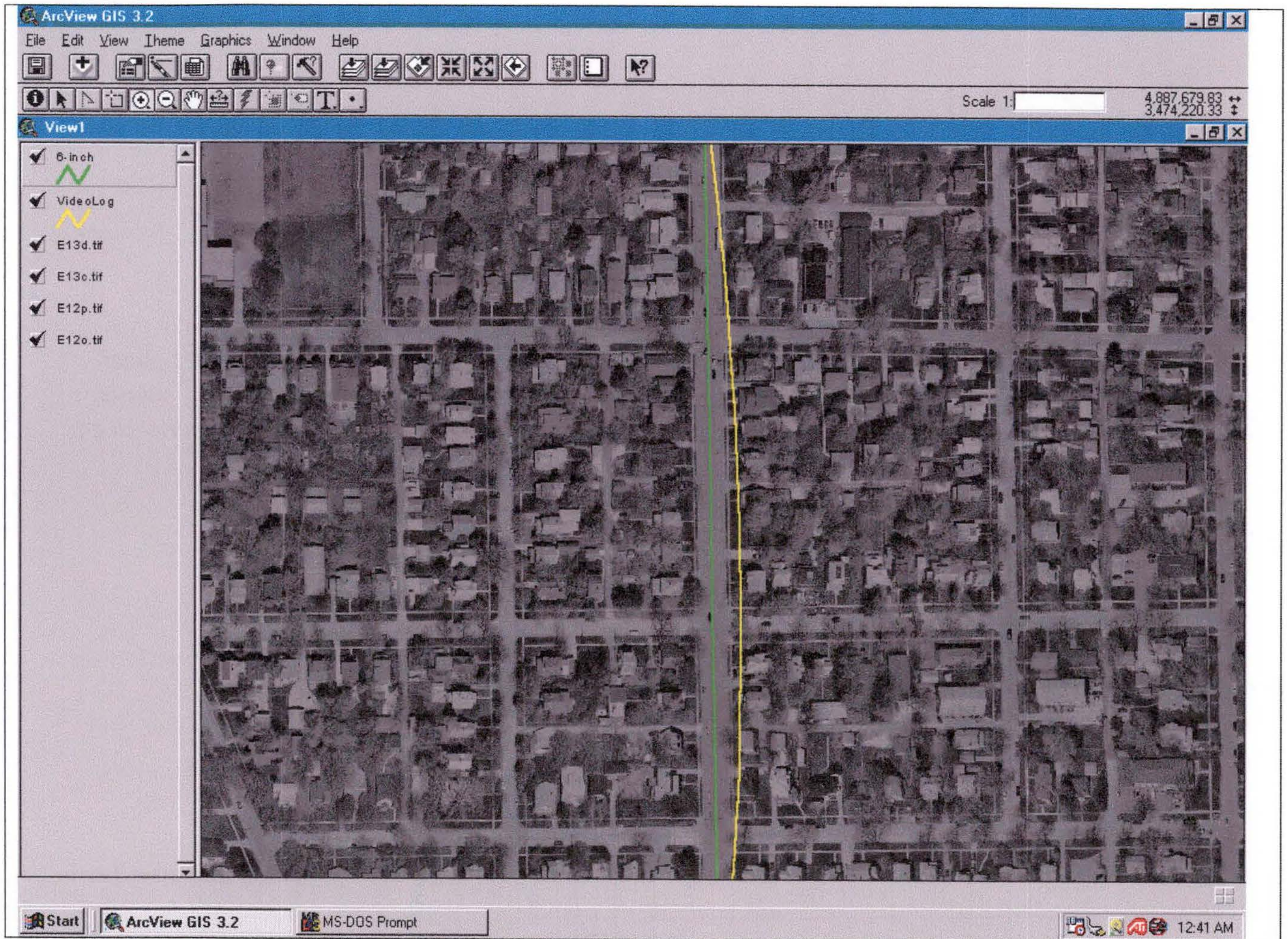


Figure 6-12: Worst Case Grand Alignment (Videolog represents the Iowa DOT Pilot Study DGPS)

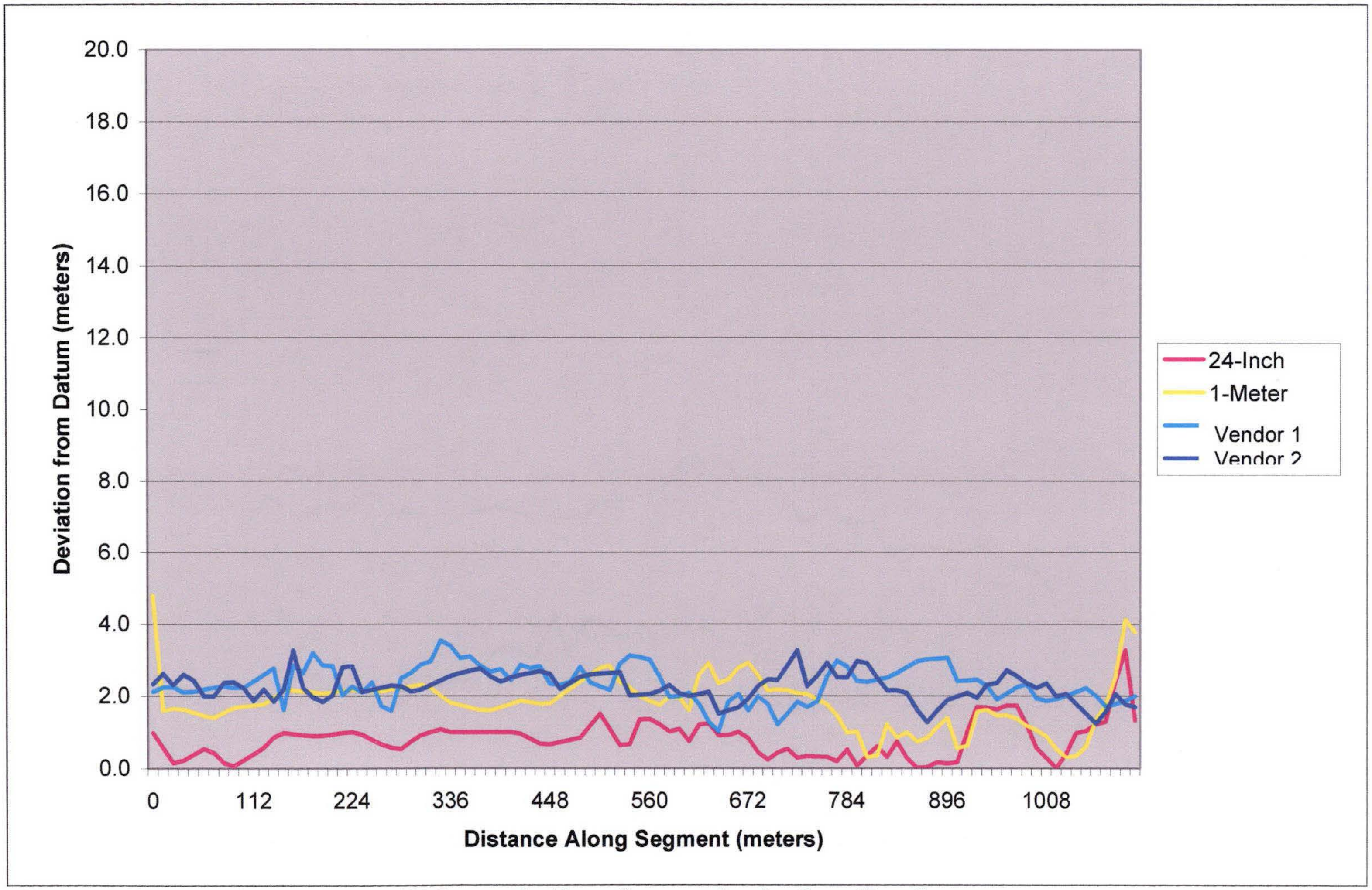


Figure 6-13: Plot of Deviation by 1% Intervals Along Segment for the State Test Segment

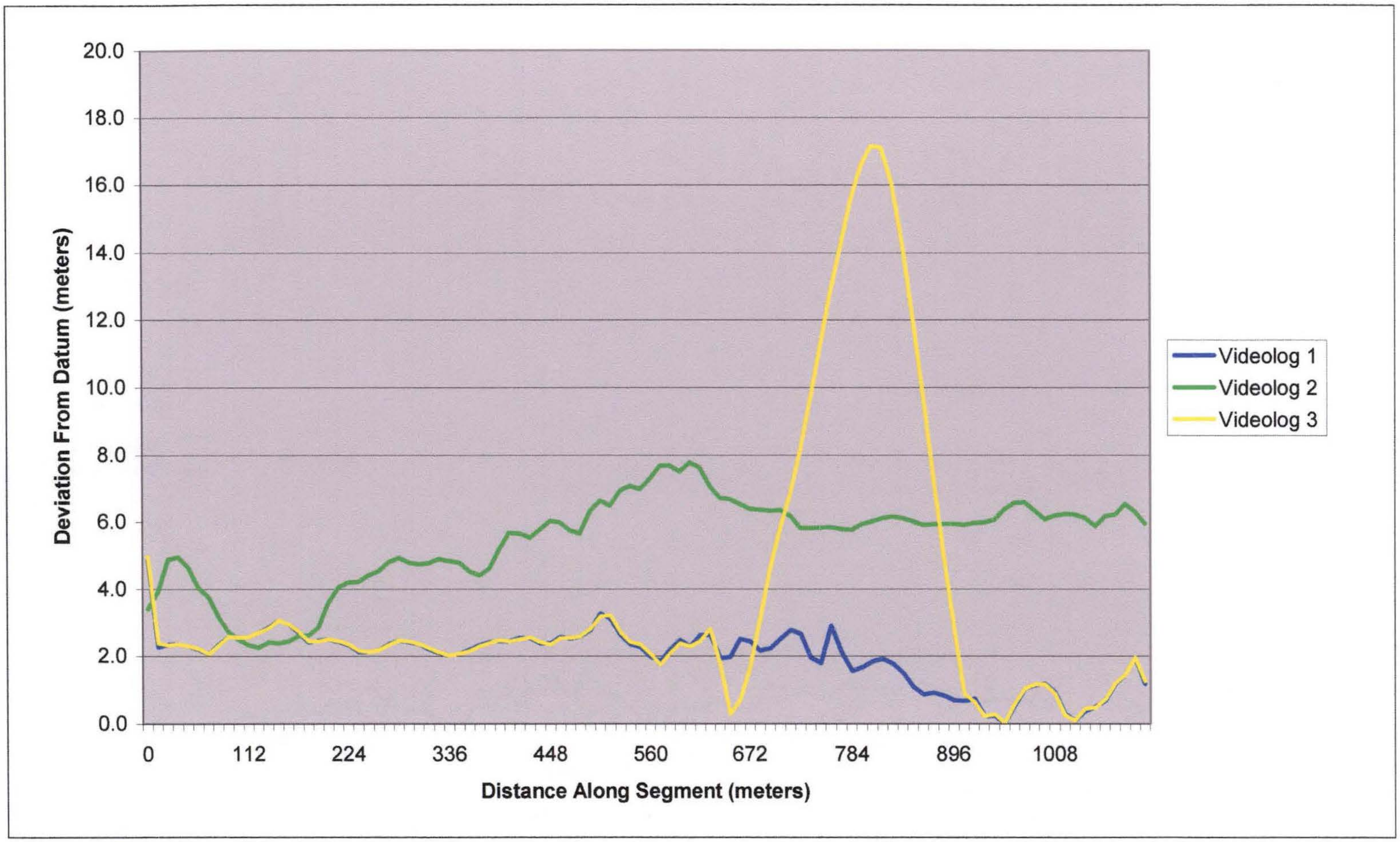


Figure 6-14: Plot of Deviation by 1% Intervals Along Segment for the State Test Segment (Videolog indicates Iowa DOT DGPS Segments)

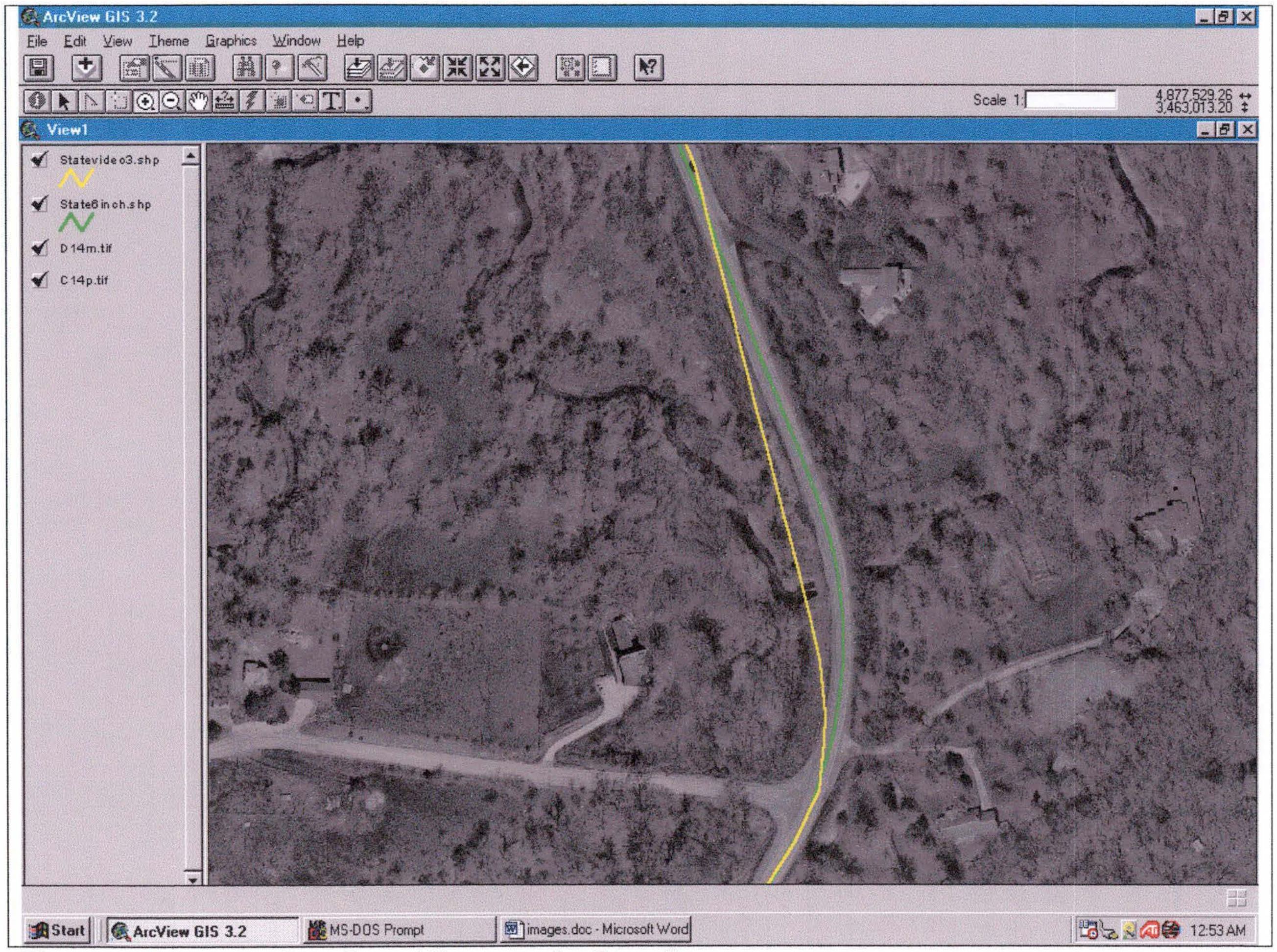


Figure 6-15: Worst Case State Alignment for State Street

6.2.6 Thackery

The Thackery Corridor was characterized by two roughly right angle changes in horizontal alignment as well as gradual horizontal curves. Vendor DGPS data were not collected for the Thackery Corridor. Mean, maximum, and minimum deviations from the baseline are provided in Table 6-6. As shown in Figures 6-16 and 6-17, the two Iowa DOT Pilot Study DGPS segments deviated the most, with changes from ~ 0 to 7.90 meters (~ 0 to 25.9 feet) around a mean of 3.35 meters (11.0 feet) for the first DGPS segment.

Table 6-6: Results for the Thackery Test Segment

	Datasets			
	24-Inch	1-Meter	DOT Pilot Study DGPS 1	DOT Pilot Study DGPS 2
Mean Deviation (meters)	0.41	2.41	3.35	1.57
Minimum Deviation (meters)	0.0	0.80	0.03	0.12
Maximum Deviation (meters)	1.49	3.75	7.90	3.78

6.2.7 Todd Drive

The Todd Drive Corridor was characterized by significant changes in horizontal alignment. Table 6-7 provides the mean, minimum, and maximum deviations for each segment. As shown in Table 6-7 and Figures 6-18 to 6-20, the vendor DGPS segments had the most deviation around the mean. The maximum deviation for the two vendor DGPS segments was around 10 meters (33 feet) for both segments with a mean of 1.88 and 3.06 meters respectively (6.2 and 10.0 feet).

Table 6-7: Results for the Todd Drive Test Segment

	Dataset					
	24-Inch	1-Meter	Vendor DGPS 1	Vendor DGPS 2	DOT Pilot Study DGPS 1	DOT Pilot Study DGPS 2
Mean Deviation (meters)	0.30	2.41	1.88	3.06	3.83	1.24
Minimum Deviation (meters)	0.0	0.79	0.0	0.09	1.37	0.06
Maximum Deviation (meters)	0.79	3.75	9.42	9.54	8.53	5.49

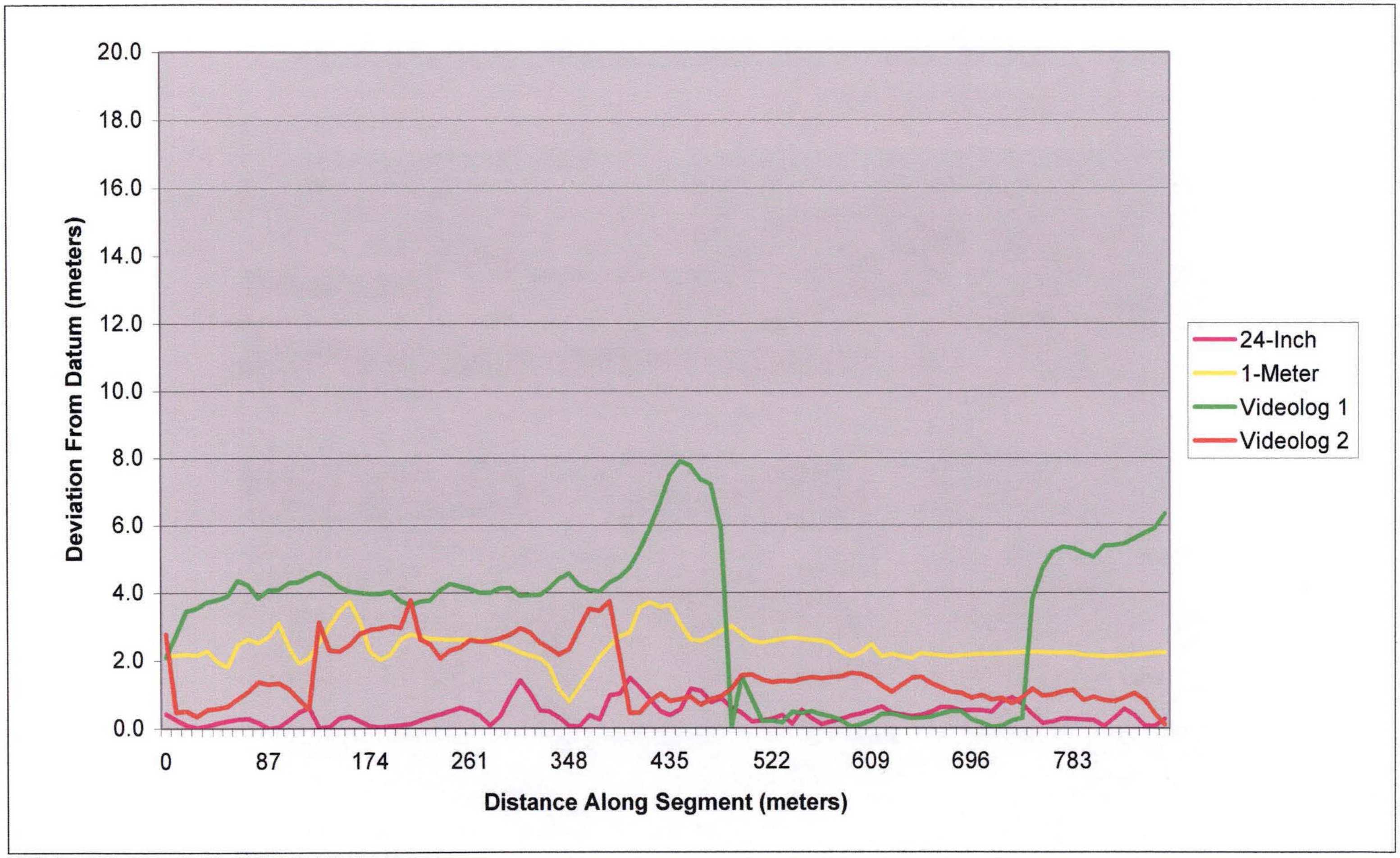


Figure 6-16: Plot of Deviation by 1% Intervals Along Segment for the Thackery Test Segment (Videolog Indicates Iowa DOT Pilot Study DGPS)

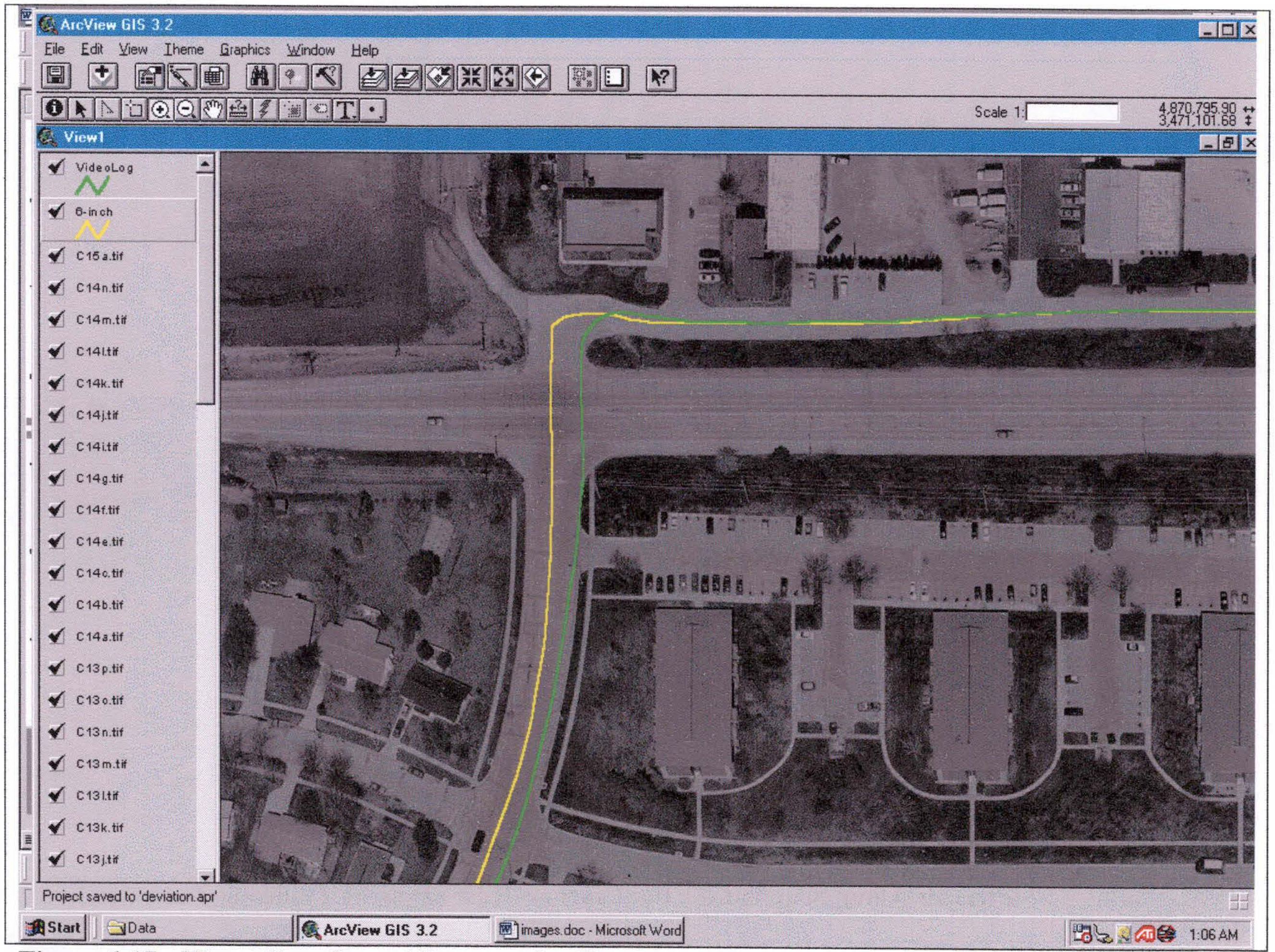


Figure 6-17: Worst Case State Alignment for Thackery (Videolog Indicates Iowa DOT DGPS)

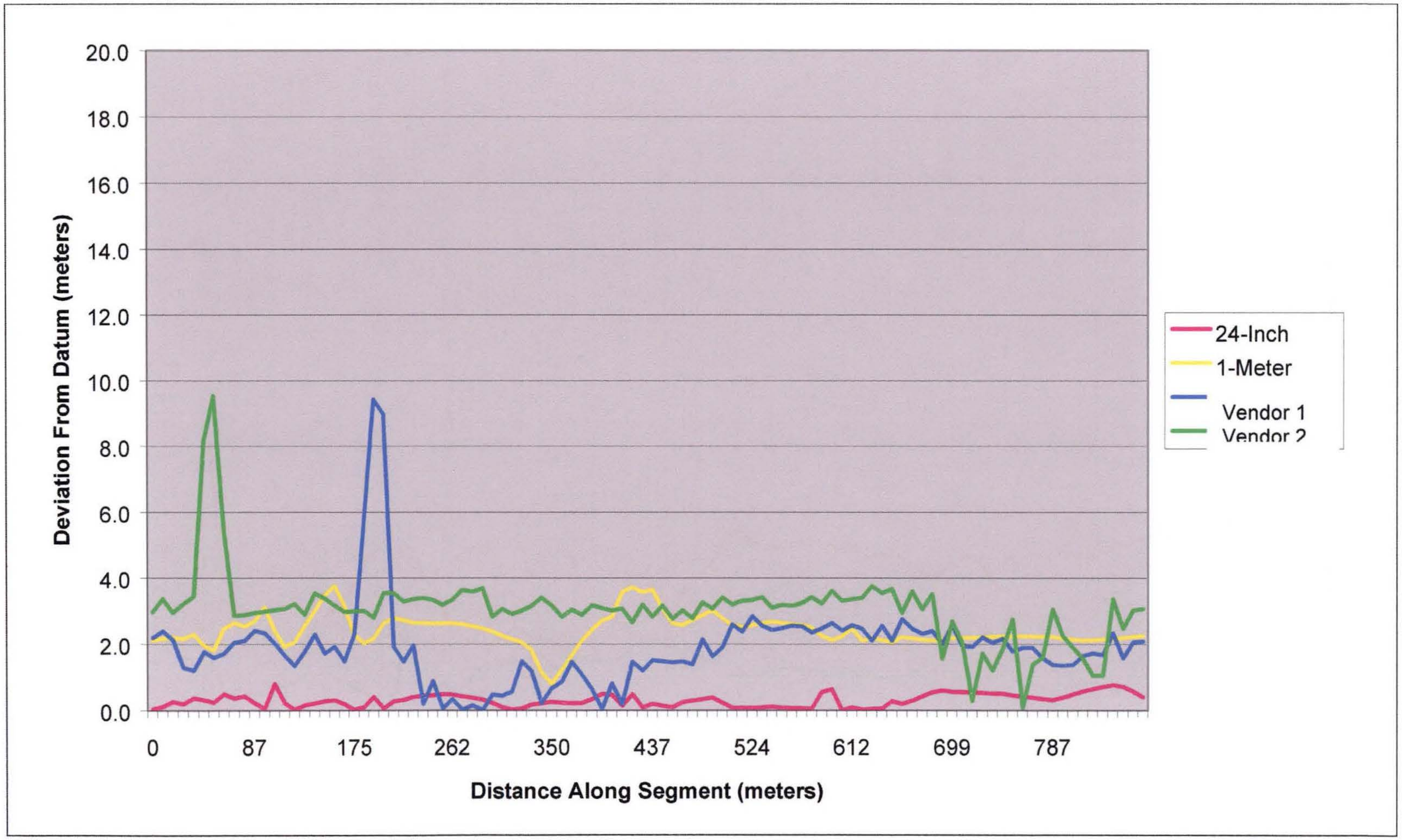


Figure 6-18: Plot of Deviation by 1% Intervals Along Segment for the Todd Drive Test Segment

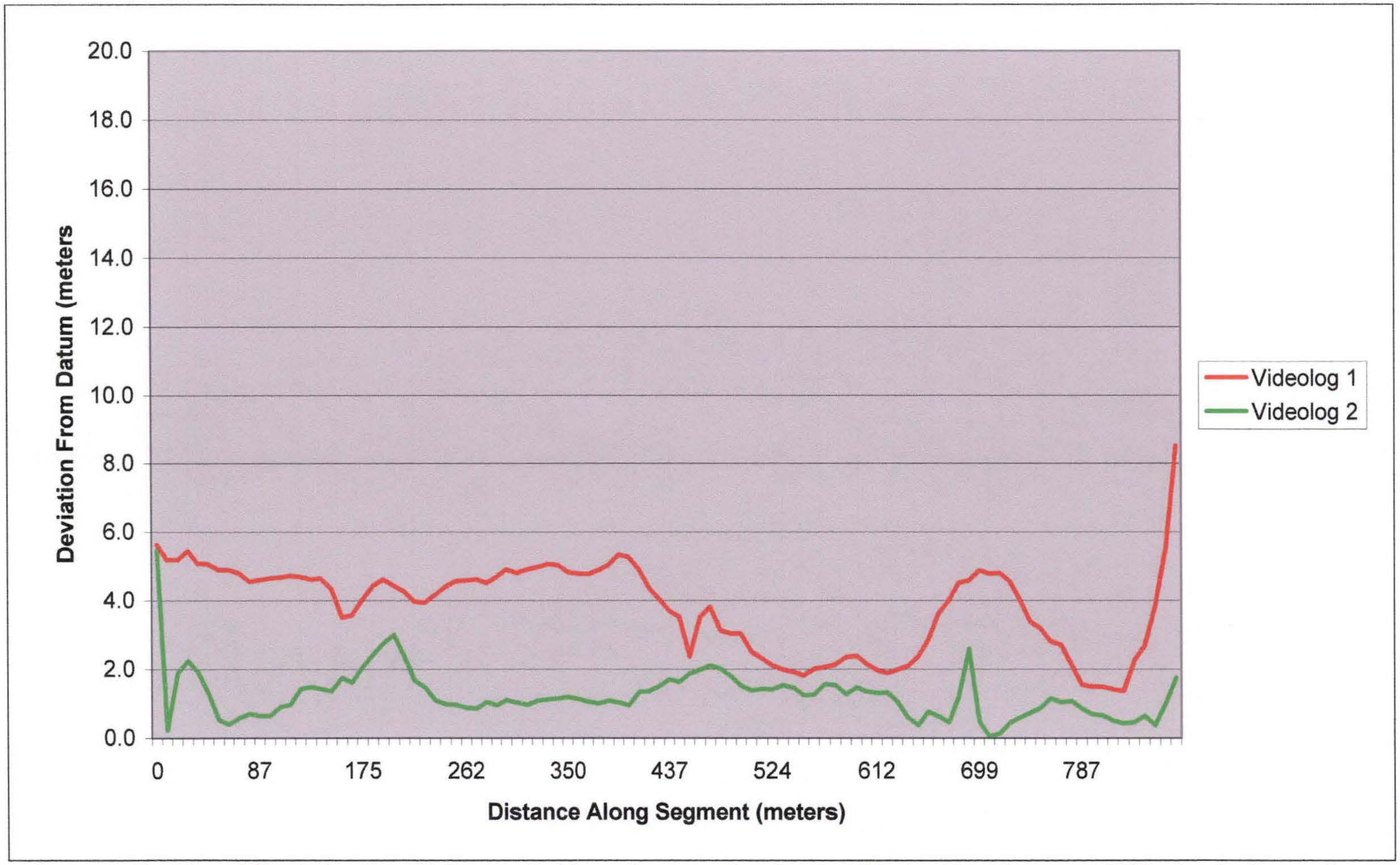


Figure 6-19: Plot of Deviation by 1% Intervals Along Segment for the Todd Drive Test Segment (Videolog Indicates Iowa DOT Pilot Study DGPS)

Figure 6-20: Worst Case State Alignment for Todd Drive (Videolog Indicates Iowa DOT Pilot Study DGPS)

6.2.8 Union

The Union Corridor was characterized by horizontal curvature but no significant vertical changes in alignment . Table 6-8 provides the mean, minimum, and maximum deviations for each segment. As shown in Table 6-8 and Figures 6-21 to 6-23, all segments except for the 24-Inch dataset segment had significant variation. The maximum variation from the mean was for the first Videolog segment with a deviation of 9.85 meters (32.3 feet) (approximately 4 meters (13 feet) from the mean).

Table 6-9: Results for the Union Drive Test Segment

	Dataset					
	24-Inch	1-Meter	Vendor DGPS 1	Vendor DGPS 2	DOT Pilot Study DGPS 1	DOT Pilot Study DGPS 2
Mean Deviation (meters)	0.55	2.09	3.97	2.55	5.77	1.16
Minimum Deviation (meters)	0.0	0.06	0.46	0.0	2.65	0.03
Maximum Deviation (meters)	1.74	5.58	5.76	6.55	9.85	4.18

6.3 Other Locations

Although not directly measured, significant deviation occurred in data collected in Nevada using the Videolog DGPS for the Iowa DOT Pilot Study. Deviations from the centerline, as estimated using 6-inch images, up to 131 meters (430 feet) were observed as shown in Figures 6-24 to 6-26.

6.4 Summary of Results for Comparison of Centerline Representations

Of the methods tested, the cartographic products produced by both the vendor provided and Iowa DOT Pilot Study DGPS methods performed the worst when compared to the baseline segments created using the 6-inch imagery even when offset was considered. The biggest problem with the use of DGPS was that unexpected erratic deviations frequently occurred. Although not documented, it is possible that the large deviations are a result of the GPS losing lock with the satellites tracked, poor PDOP, multi-path error, or method of differential correction.

The centerline representations created using the 24-inch dataset were the most consistent with the 6-inch baseline. Maximum and average deviations from the baseline were typically less than 3 meters (9.8 feet) and frequently 1.5 meters or less (4.9 feet). The 1-meter dataset did not perform as well but average deviation was usually only around 2 meters (6.6 feet) with maximum deviations fluctuating from 4 to 8 meters (13.1 to 26.2 feet).

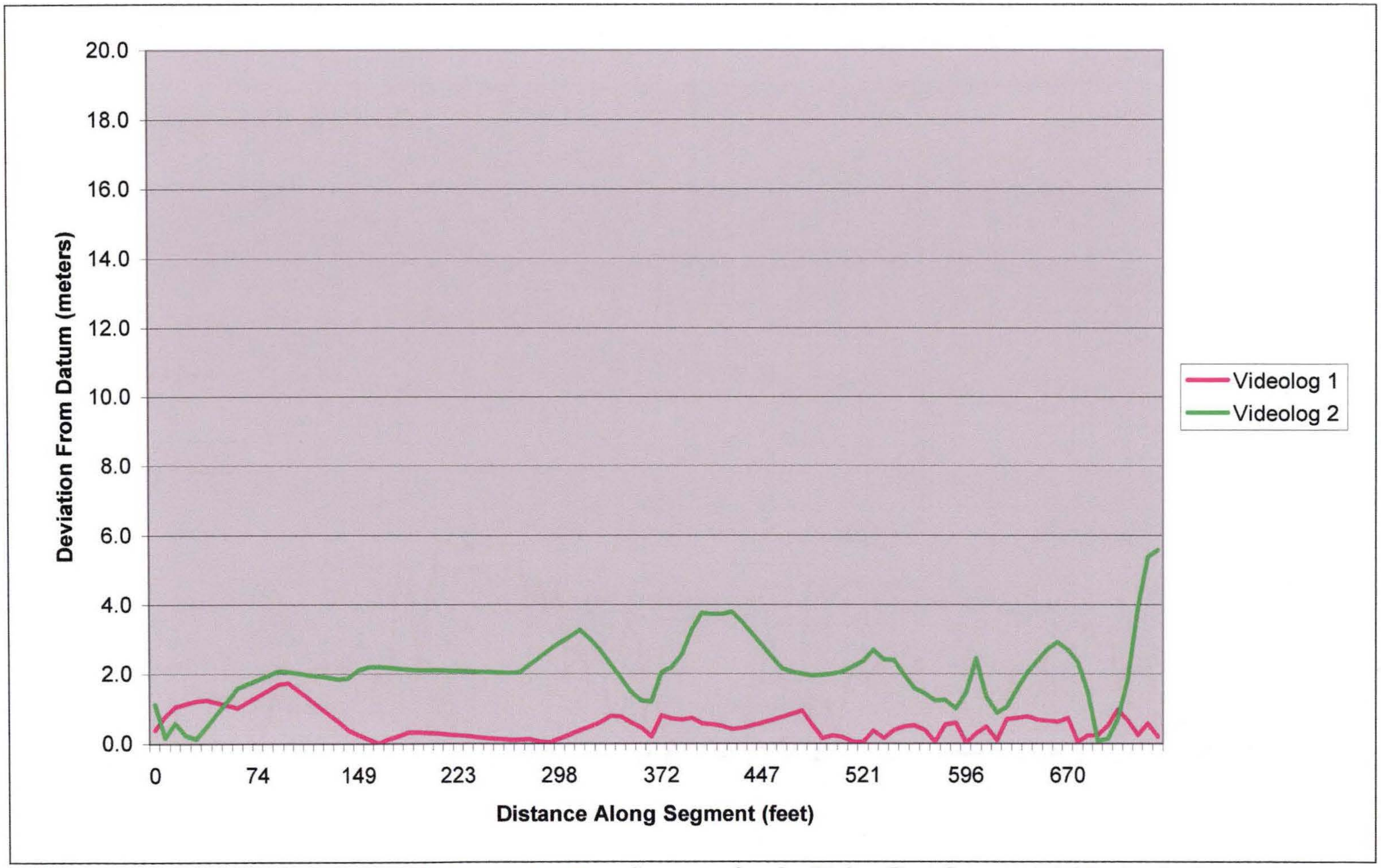


Figure 6-21: Plot of Deviation by 1% Intervals Along Segment for the Union Test Segment (Videolog Indicates Iowa DOT Pilot Study DGPS)

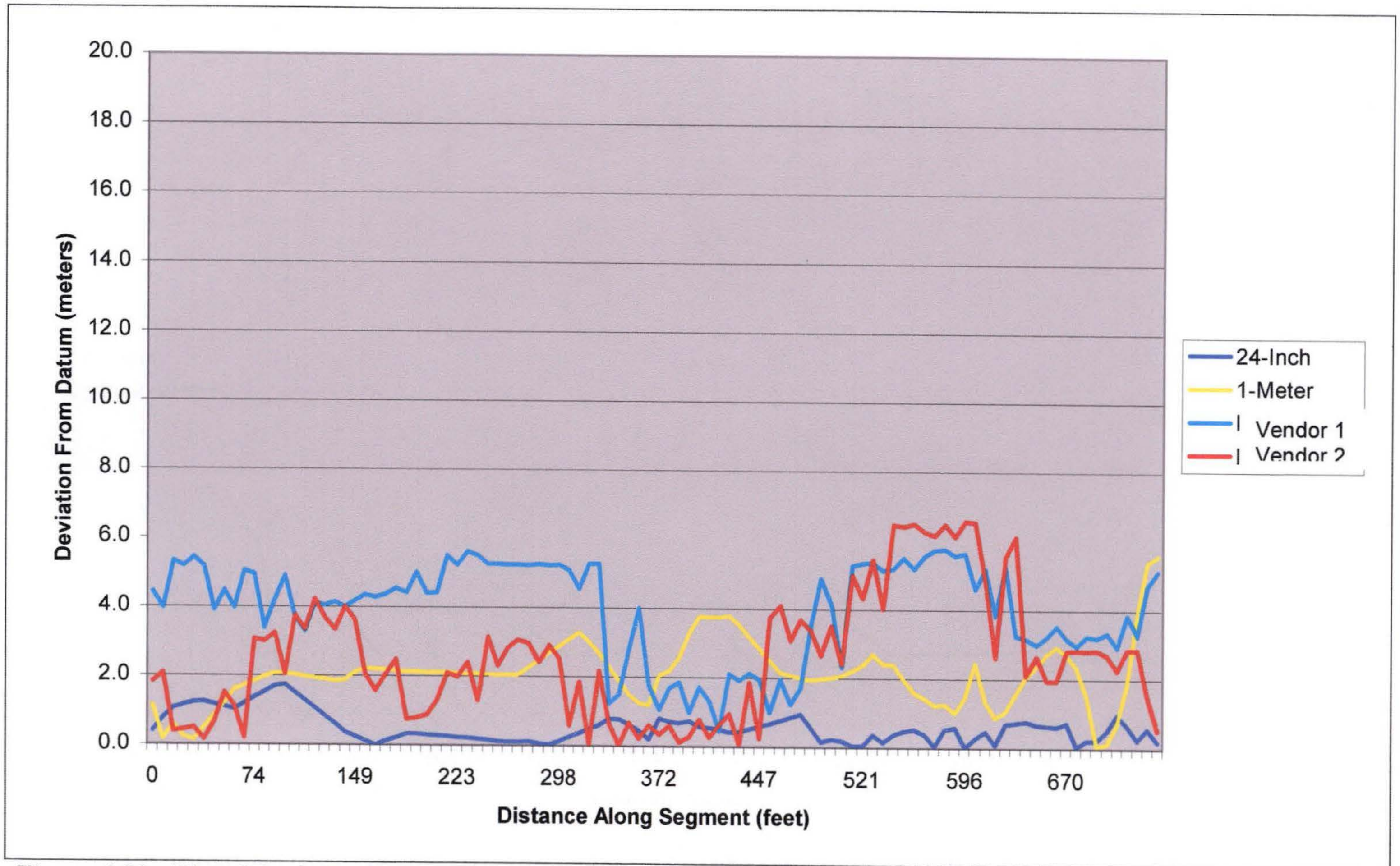


Figure 6-22: Plot of Deviation by 1% Intervals Along Segment for the Union Test Segment

Figure 6-23: Worst Case State Alignment for Union

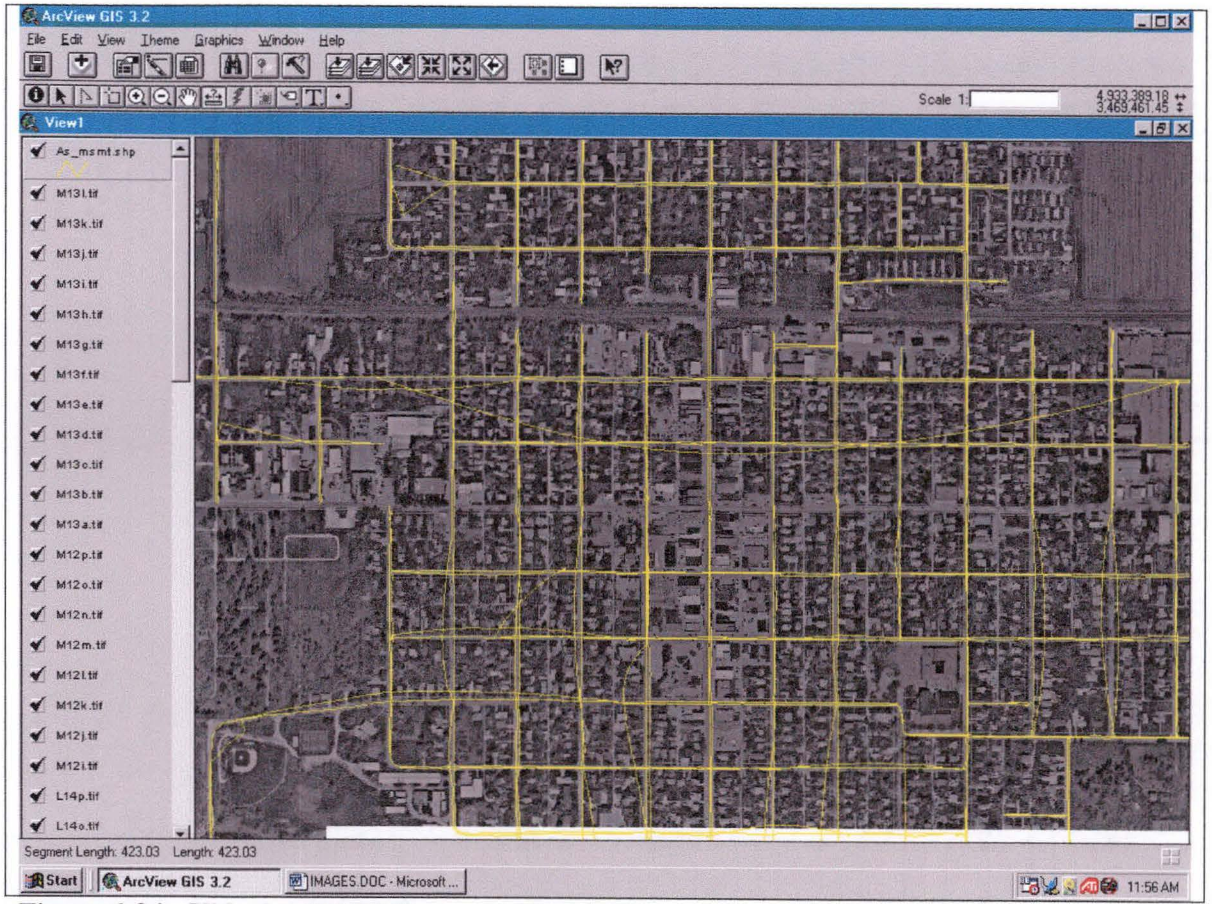


Figure 6-24: Videolog DGPS Traces in Nevada

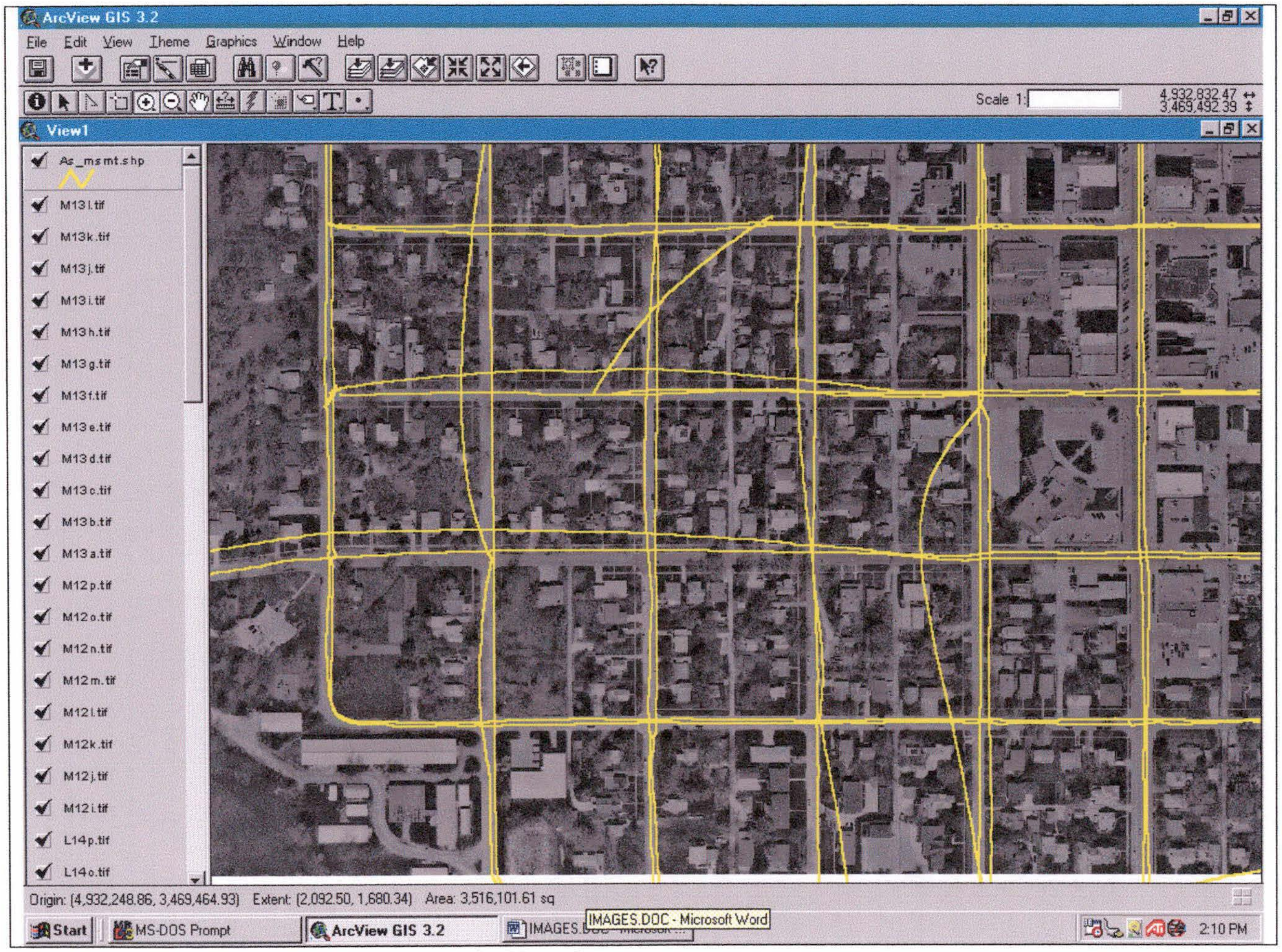


Figure 6-24: Videolog DGPS Traces in Nevada

7. ESTABLISHING THE LOCATION OF NON-ANCHOR POINT INTERSECTIONS

The LRS will consist of anchor points and anchor section distances between those points. In many cases, the center of an intersection will serve an anchor point location. However, anchor sections will typically span a number of intermediate intersections. Locating the linear offset of intermediate intersections along a particular anchor section will be necessary to establish topography for conversion between linear referencing methods (LRM). The location of intermediate intersection may be established using several methods that are compatible with the data collection methods under consideration by the Iowa DOT LRS team for creation of the LRS datum (GeoAnalytics, et al, 2001).

7.1 Methods to Establish the Location of Non-Anchor Point Intersections

The following sections describe methods that may be used to calculate the linear offset distance of intermediate intersections along an anchor section.

7.1.1 Existing Cartography

The simplest method to establish intermediate intersections is to use existing cartography, such as the GIMS database. If anchor points are located to the cartography, distances between reference points and intermediate intersections can be established by simply measuring along the cartography. Linear offset to intermediate intersections can be transferred to the corresponding anchor section by either using calculated distances along the cartography directly or expressing linear offset as a percent. Noronha, 2000 and Ries (2001) suggest storing linear offset as a percentage, which is directly transferable to a corresponding segment where:

$$\text{Percent}_{Offset} = (\text{Offset}_i/\text{Length}_{LRM}) * 100 \qquad (7\text{-}1)$$

where:

Percent_{Offset} = % of segment length that point i is offset;
Offset_i = linear offset for point i;
Length_{LRM} = segment length.

The main advantages to using cartography are that it would be fairly inexpensive to implement, since the dataset already exists, and that the method could be done fairly rapidly. The main disadvantage is the inherent inaccuracies in the GIMS cartography.

7.1.2 Intersection of the Spatial Representation of Anchor Sections

If a spatial representation of the datum is created using one of the methods discussed in Section 5 or a similar method, a cartographic product will be available. Segments will begin and end at anchor points; crossing, but not intersecting, intermediate intersections. Most GIS packages can establish an intersection at the crossing of two line segments. The linear offset to intermediate intersections can be estimated fairly easily using this method.

The main problem with using the cartographic by-product is that it may not adequately represent the roadway centerline as discussed in Section 6. For the Iowa DOT Pilot Study DGPS and vendor DGPS methods, deviations from the centerline up to 15.24 meters (50 feet) were common. Significant deviations in the vicinity of intersections would result in inaccurate calculation of the linear offset distance to intermediate intersections. Additionally both DGPS methods produce a geographic trace of the lane traveled rather than the centerline, which requires adjusting to represent the roadway centerline.

7.1.3 Use of DMI During Data Collection

A data collection method that uses a distance measuring instrument to measure anchor section distances can also be used to record the distance along the anchor section between the BEGIN anchor point and each intermediate intersection. This method could be utilized during data collection. The main drawback is that it may become time consuming if the vehicle has to slow down or operators have to "mark" the center for every intersection. An additional problem is that it may be difficult to estimate the center of an intersection while on the ground, especially in a moving vehicle.

7.1.4 Remotely Sensed Imagery

Imagery may be used in two different ways to locate intermediate intersections along an anchor section. First, if aerial or satellite images are used to measure anchor section distances, a cartographic by-product for each anchor section would be available. The linear offset to intermediate intersections could be calculated by placing intersections where anchor sections cross and automating a method to measure the distance between intermediate intersections.

The location of intermediate intersections can be determined by visually estimating the center of each intersection or by physically measuring the center. If the edge of roadway can be determined for each intersection approach, the center of each approach and actual center of the intersection could be estimated fairly accurately.

7.2 Comparison of Cartography Versus Imagery to Locate Intermediate Intersections Along an Anchor Section

The use of the GIMS cartography versus the use of the 6-inch imagery dataset to establish the linear offset of intermediate intersections along an anchor section was compared to evaluate the two methods. Not enough data were available to test the other methods listed, such as use of a DMI.

7.2.1 Methodology

Test segments from Pilot Study 3 (Section 3.4) were used for comparison. The centerline representation created as part of the pilot study for the 6-inch dataset was used as a baseline. The location of each intermediate intersection was established using the following steps:

1) for each approach determine the edge of pavement on each side of the roadway and create a cross-section line segment perpendicular to the edge of roadway;
2) using an ArcView Avenue script, determine the center of each cross-section line from step 1. This establishes the roadway center.
3) Create a centerline segment for each pair of approaches (most intersections were 4-legged);
4) Place a point representing the center of the intersection where the two centerline segments cross as shown in Figure 7-1.
5) Calculate the linear offset along the baseline segment for each intermediate intersection.

For the GIMS cartography, the existing intersections were used. Linear offset was established using cartographic distances between intersections.

7.2.2 Results

Differences between linear offsets established using the 6-inch imagery and GIMS cartography for the 8th Street section are shown in Table 7-1. Similar tables for the remaining sections are provided in Appendix C. The difference between the linear offset location for intermediate intersections between the 6-inch baseline and the GIMS cartography varied from around 13.7 to 32.3 meters (45 feet to 106 feet). Additionally, two intersections were present in the imagery, which were not present in the GIMS cartography. This may indicate that the cartography lacks currency to a certain extent.

The variation for the Airport Road section ranged from -8.53 to 4.57 meters (–28 to 15 feet). The differences between the linear offset calculated using the 6-inch imagery and the cartography for the K Avenue section only varied between –0.91 and 5.18 meters (–3 and 17 feet). For the L Avenue section, the differences ranged from –7.62 to 0.30 meters (–25 to –1 feet). The Todd Drive section was characterized by more significant differences, which varied from 3.35 up to 19.51 meters (11 feet up to 64 feet). One intersection was present in the imagery along Todd Drive, which was not present in the cartography. Finally, differences ranged from –3.05 to 20.12 meters (–10 to 66 feet) for the Union segment. Histograms depicting the magnitude of differences for each segment are provided in Figure 7-1 to 7-6.

Table 7-1: Difference Between Linear Offset to Intermediate Intersections For 8th Street

ID	Datum		Cartography		Datum Offset Minus Cartography (m)
	Segment Length (m)	Linear Offset to Intersection (m)	Segment Length (m)	Linear Offset to Intersection (m)	
2	1751.4	533.8	1719.8	506.7	27.2
3	1751.4	616.1	1719.8	588.2	28.0
4	1751.4	709.7	*Cartography missing intersection*		
5	1751.4	959.4	*Cartography missing intersection*		
6	1751.4	868.3	1719.8	854.8	13.6
7	1751.4	1063.8	1719.8	1038.8	25.0
8	1751.4	1302.7	1719.8	1275.8	26.9
9	1751.4	1416.5	1719.8	1388.6	27.9
10	1751.4	1528.6	1719.8	1496.2	32.4
11	1751.4	1641.4	1719.8	1613.2	28.2

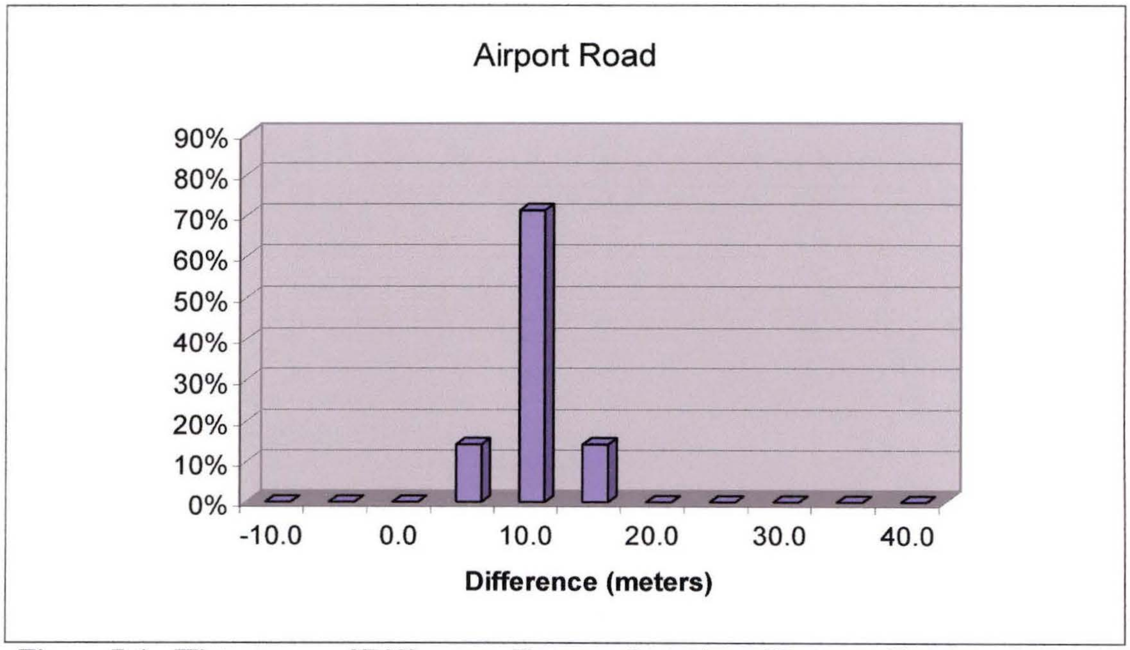


Figure 7-1: Histograms of Differences Between Location of Intermediate Intersections on Baseline Versus Cartography for Airport Road

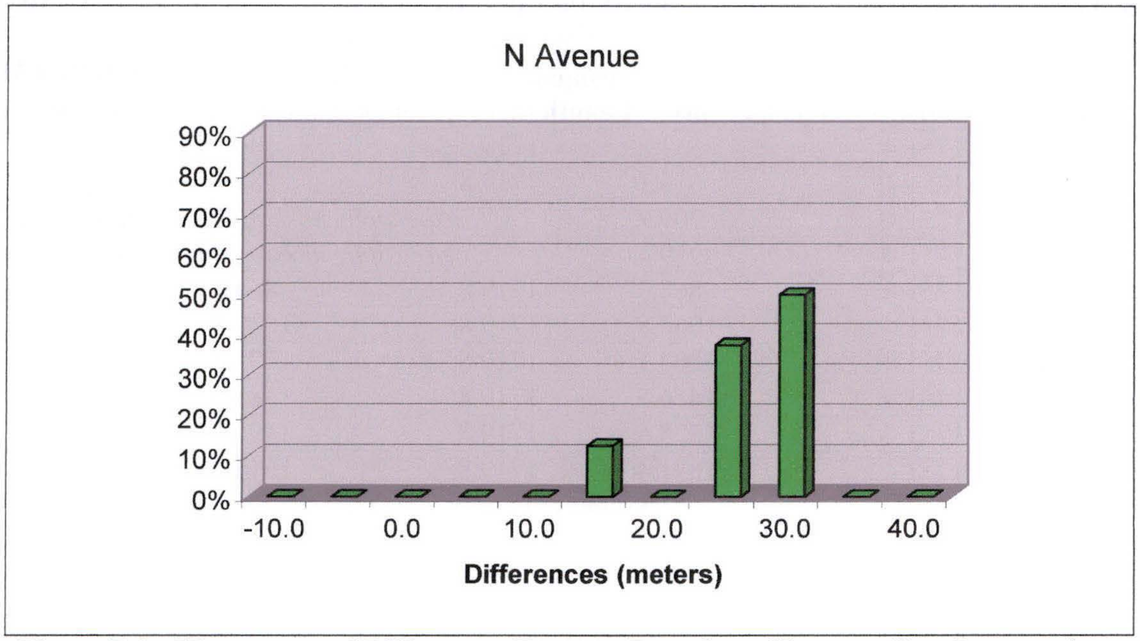


Figure 7-2: Histograms of Differences Between Location of Intermediate Intersections on Baseline Versus Cartography for N Avenue

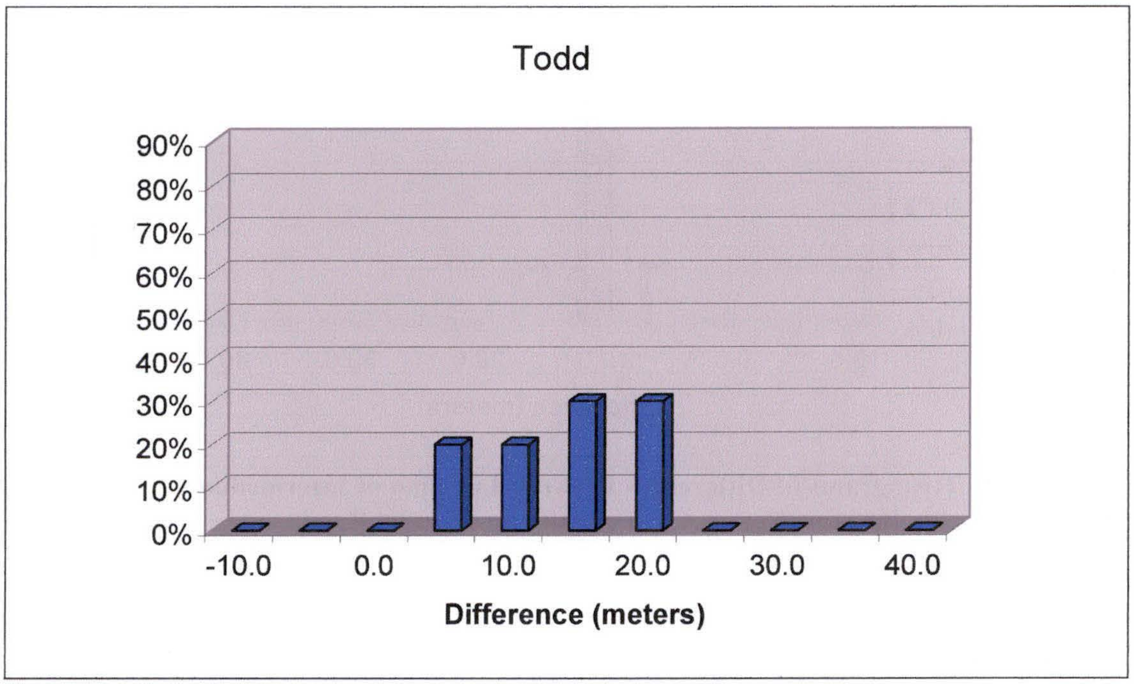


Figure 7-3: Histograms of Differences Between Location of Intermediate Intersections on Baseline Versus Cartography for Todd Drive

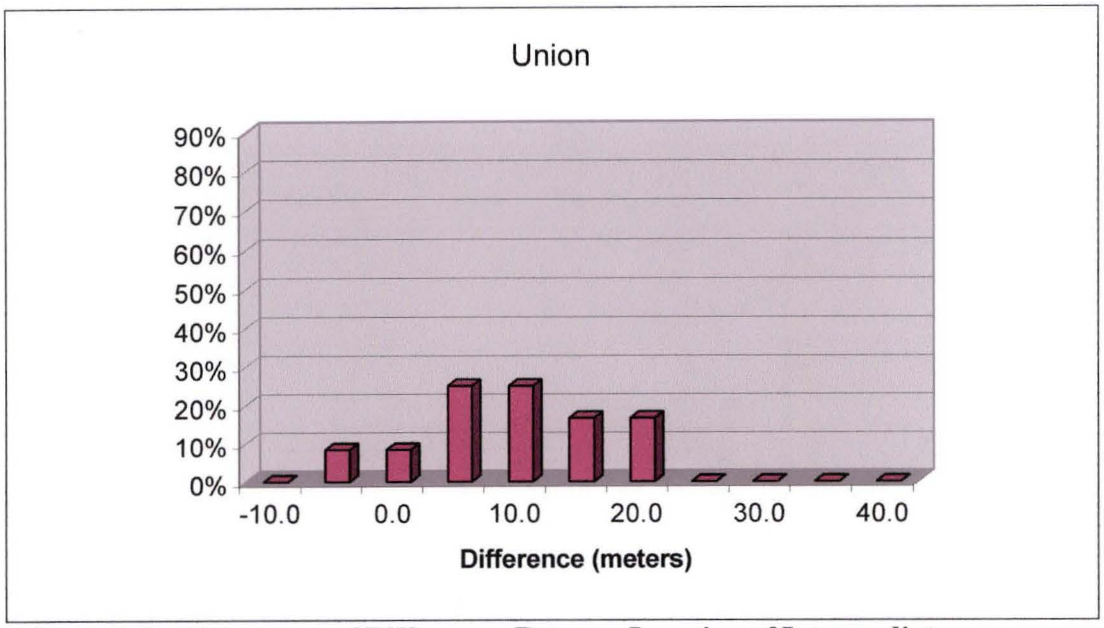


Figure 7-4: Histograms of Differences Between Location of Intermediate Intersections on Baseline Versus Cartography for Union

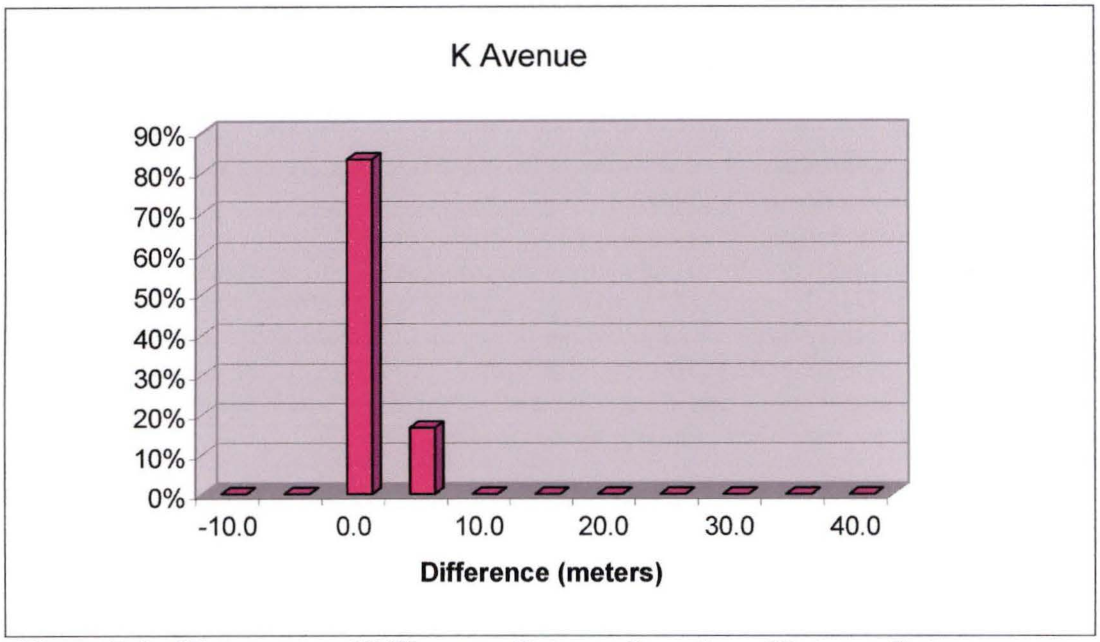


Figure 7-5: Histograms of Differences Between Location of Intermediate Intersections on Baseline Versus Cartography for K Avenue

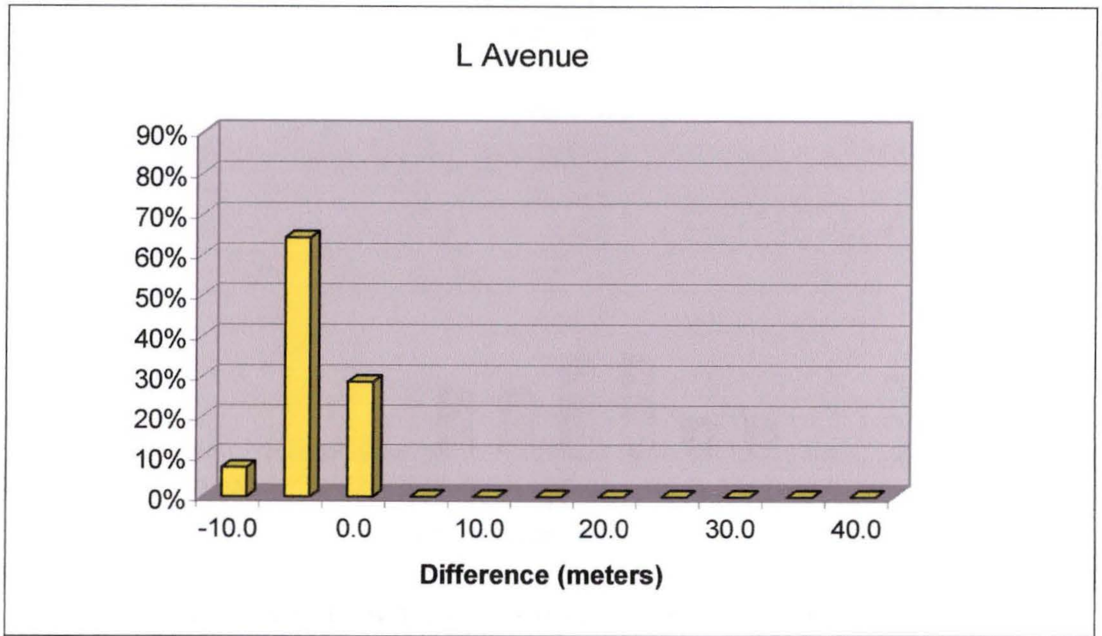


Figure 7-6: Histograms of Differences Between Location of Intermediate Intersections on Baseline Versus Cartography for L Avenue

7.6 Summary

Several methods may be available to calculate the linear offset of intermediate (non-anchor point) intersection along anchor sections, including use of a DMI during data collection, measurement of intersection to intersection segments using cartography, use of cartographic by-products created while digitizing imagery or created using a string of GPS coordinates from video-logging.

The use of cartography to calculate linear offset was compared against a baseline created using the 6-inch images. The offsets calculated using cartography were frequently significantly larger or smaller than those calculated along the baseline. Differences up to 30.58 meters (100 feet) were noted. Additionally, the cartography was missing several intersections that were present in the imagery, which may have been due to lack currency for the GIMS cartography.

8. SUMMARY

This report evaluated the use of remotely sensed images for use in implementing the Iowa DOT LRS that is currently in the stages of system architecture. Specifically, the use of imagery for creation of the datum, including locating anchor points and measuring anchor sections; producing a spatial representation of the datum; and locating intermediate intersections along the datum were investigated. Three imagery datasets were evaluated in the various studies. They included a 6-inch resolution dataset, a 24-inch resolution dataset, and a 1-meter resolution dataset. The 1-meter dataset simulated the best data satellite data available commercially. A 2-inch resolution dataset was evaluated for several of the studies. However, coverage in the images was limited so it could not be fully evaluated.

The use of imagery to establish the geographic location of anchor points and business data was tested. The positional accuracy of the 2-inch, 6-inch, and 24-inch datasets was such that they met the Iowa DOT LRS specifications of ± 1.0 meter RMS. The RMS of the 1-meter dataset exceeded the requirement by only 0.9 meters. Although the lower resolution datasets were comparable to the higher resolution datasets as far as accuracy is concerned, the limiting factor in their use is that many features could either not be identified in the images or could not consistently be identified. In the 1-meter dataset, only major features such as the center of intersections, land use, general intersection geometry, and railroad crossings could be consistently seen and identified. Items such as signal posts, drainage structures, and utility poles could not be identified in the images. Results were only marginally improved for the 24-inch imagery dataset. In the 6-inch, all features could be identified, although some not consistently (signs, utility poles, median type, on-street parking). In the 2-inch dataset most features could be consistently identified.

The magnitude of human error on the ability to spatially locate features was also evaluated. Eight different features were selected to test the variation that occurs between different operators who are reducing the same data from imagery. Only three of the features could be identified and used in the 24-inch and 1-meter dataset. Of those three features, observers were able to locate railroad crossings with the least variation. The average variation between observers was less than 0.5 meters (1.6 feet) for the 2-inch, 6-inch, and 1-meter images. The 24-inch dataset, however, performed much worse with an average of 1.34 meters (4.4 feet). For the other two features, bridges and the center of an intersection, all datasets performed poorly (average deviation 0.43 to 1.34 meters (1.4 to 4.4 feet). Five other features could be identified in the 6-inch and 2-inch images (drainage structures, driveways, traffic signal posts, medians, and pedestrian crossing). The average variation between observers for those features was 0.52 meters (1.7 feet) or less for the two datasets.

Again, the limiting factor in the use of imagery was the inability to even identify specific features in the lower resolution images enough to establish position. Variation appears to be less significant for features that are well defined, such as a utility pole or drainage structure, variation increased with features that were less distinct, such as the center of an intersection. Making explicit rules for locating features may decrease variation among users. The ability to locate less distinct features accurately may also influence the choice of features used as anchor points.

The use of imagery to calculate anchor section distances was also investigated. Centerlines were created using heads-up digitizing for each image dataset (not including the 2-inch) and measured. Segment lengths from videologging were available from the Iowa DOT Pilot Study project for comparison. A small sample of test roadway segments was driven by a vendor's DMI/DGPS van as well. The difference between the calculated distance for each dataset and the Iowa DOT pilot study videolog DMI measurements was calculated. Although the mean difference in lengths was less than 2.0 meters for the three image datasets, none met the RMS requirement for the Iowa DOT LRS. The vendor videolog segments performed significantly worse with a mean of –10.58 meters (-34.7 feet) and a standard deviations of 13.18 meters (43.2 feet). However, vendor data were only available for four segments for comparison.

Creation of a spatial representation of the LRS datum using the different methods was tested as well. Videologging vans with DGPS are capable of producing a cartographic byproduct. The roadway centerline can also be digitized if imagery is used to measure anchor section distances. A centerline created using the 6-inch dataset was used as the baseline for comparison with the other methods. The 24-inch and 1-meter dataset performed adequately. The general horizontal curvature of the road was followed. Deviations from the 6-inch centerline in most cases were not significant. The Iowa DOT pilot study videolog and vendor videolog van data however did not perform well. Deviations of 10 meters (33 feet) were common with maximum deviation up to18 meters (60 feet) noted. Occasionally, erratic departures from the roadway alignment occurred.

Finally, the use of different methods to establish the location on intermediate, non-anchor point intersections along the datum were discussed and linear offsets calculated using the 6-inch centerline and linear offsets calculated using intersection spacing in the GIMS database were compared. Differences of 8 to 20 meters (25 to 65 feet) were common with differences up to 30 meters (100 feet) reported.

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APPENDIX A: POSITIONAL ACCURACY CALCULATIONS

Table A.1: GPS coordinates in State Plane Iowa North system and NAD 1983 datum

GPS Coordinates for Planimetric Points			
ID	North	East	Elevation
1	3463500.760	4890581.180	902.670
2	3463496.960	4891232.530	903.240
3	3465417.980	4890381.980	903.440
4	3464219.960	4891644.850	895.470
5	3466165.190	4890919.140	903.850
6	3466132.550	4892018.840	887.900
7	3466790.710	4890955.890	898.560
8	3467603.500	4890951.020	893.680
9	3468784.650	4891223.620	887.620
10	3468940.300	4891320.050	886.690
11	3469431.740	4890755.990	888.140
12	3469866.100	4891209.690	888.370
13	3470978.680	4890755.570	901.350
14	3471377.860	4890755.490	906.910
15	3472008.400	4890392.280	917.500
16	3472095.160	4891210.590	919.530
17	3471477.110	4888629.180	910.160
18	3471472.060	4888468.360	910.600
19	3472511.550	4889173.260	920.710
20	3472438.350	4888634.410	919.870
21	3473614.390	4889064.870	922.820
22	3473592.320	4888238.080	927.940
23	3474108.680	4888539.530	926.320
24	3474738.240	4888589.330	930.840
25	3475654.620	4889461.810	936.790
26	3475689.900	4888267.510	941.810
27	3477059.490	4889021.470	945.720
28	3477008.060	4888265.630	953.730
29	3481760.110	4889025.730	958.160
30	3481754.210	4888317.410	954.120
31	3481036.940	4888603.690	962.750
32	3481673.140	4887439.790	951.910
33	3470796.820	4884890.320	895.720
34	3471371.320	4886731.970	903.510
35	3471432.490	4886824.480	903.530
36	3471365.000	4886492.020	904.160
37	3468607.630	4891225.180	887.800
38	3469430.490	4891370.670	885.880
39	3470449.740	4890988.610	901.310
40	3470915.720	4890347.630	911.250

GPS Coordinates for Planimetric Points			
ID	North	East	Elevation
41	3472157.500	4889145.720	915.030
42	3473225.620	4888541.310	925.470
43	3475226.860	4888516.690	936.190
44	3477403.660	4887878.560	956.110
45	3477394.150	4887109.140	959.700
46	3477760.320	4889460.500	958.500
47	3474084.260	4889425.260	925.840
48	3472807.050	4887992.070	927.350
49	3471439.240	4887983.060	913.930
50	3472807.450	4889439.370	921.390
51	3470445.430	4890339.160	910.540
52	3463496.700	4890272.010	904.180
53	3466146.060	4890599.470	904.690
54	3480010.180	4888546.850	961.670
55	3470286.340	4885153.290	896.170

Table A.2: Positional Accuracy for 2-inch resolution aerial photograph

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+ (Diff in Y)^2
		GPS	2 Inch aerial			GPS	2 Inch aerial			
1	(D) Airport Road, Near to Sams club Parking Lot	4890581.180	4890579.402	1.778	3.160	3463500.760	3463500.708	0.052	0.003	3.163
6	(D) S. 16th Street West, Away from the X	4892018.840	4892017.990	0.850	0.722	3466132.550	3466131.691	0.859	0.738	1.461
7	(D) Near to K-Mart Parking Lot on Buckeye	4890955.890	4890955.810	0.080	0.006	3466790.710	3466790.659	0.051	0.003	0.009
8	(D) On Buckeye, to the end, near Red Lobster	4890951.020	4890949.857	1.163	1.353	3467603.500	3467603.472	0.028	0.001	1.354
17	(D) Lincoln Way & Grand Ave, Near H-Video	4888629.180	4888629.038	0.142	0.020	3471477.110	3471477.050	0.060	0.004	0.024
18	(S) Lincoln Way & Grand Ave, Near Credit Union	4888468.360	4888468.169	0.191	0.036	3471472.060	3471471.572	0.488	0.239	0.275
21	(S) Wilson Ave & 8th St	4889064.870	4889064.693	0.177	0.031	3473614.390	3473614.933	-0.543	0.295	0.326
22	(S) Hodge Ave & 8th St	4888238.080	4888238.258	-0.178	0.032	3473592.320	3473591.994	0.326	0.106	0.138
23	(S) Grand Ave & 9th St	4888539.530	4888539.675	-0.145	0.021	3474108.680	3474108.690	-0.010	0.000	0.021
24	(S) Grand Ave & 11th St	4888589.330	4888590.055	-0.725	0.526	3474738.240	3474739.537	-1.296	1.681	2.207
26	(S) Harding Ave & 13th St	4888267.510	4888266.998	0.512	0.263	3475689.900	3475688.399	1.501	2.252	2.515
27	(S) Wilson Ave & 16th St	4889021.470	4889020.263	1.207	1.458	3477059.490	3477058.216	1.274	1.622	3.080
28	(S) Harding Ave & 16th St	4888265.630	4888266.211	-0.581	0.338	3477008.060	3477008.783	-0.723	0.522	0.860
29	(S) Duff Ave & Jenson Ave	4889025.730	4889024.950	0.780	0.608	3481760.110	3481759.982	0.128	0.016	0.624
30	(S) Bus Stop near Wal-Mart parking lot	4888317.410	4888318.065	-0.655	0.429	3481754.210	3481754.101	0.109	0.012	0.441
31	(A) Access road on 28th St, next to Grand Ave	4888603.690	4888604.460	-0.770	0.592	3481036.940	3481037.361	-0.421	0.177	0.769
32	(S) 30th St & Ferndale Ave	4887439.790	4887439.566	0.224	0.050	3481673.140	3481673.097	0.043	0.002	0.052
33	(S) Side Walk next to Hilton Coliseum, East End	4884890.320	4884890.212	0.108	0.012	3470796.820	3470796.590	0.230	0.053	0.065
34	(S) Lincoln Way, near to Hazel Ave	4886731.970	4886731.781	0.189	0.036	3471371.320	3471371.320	0.000	0.000	0.036
35	(S) Lincoln Way & Hazel Ave	4886824.480	4886824.187	0.293	0.086	3471432.490	3471432.479	0.012	0.000	0.086
36	(A) Access road from house to Lincoln Way	4886492.020	4886492.664	-0.644	0.415	3471365.000	3471365.123	-0.123	0.015	0.430

Table B.2: (continued)

Point ID	Point Description	X - Coordinate GPS	X - Coordinate 2 Inch aerial	Diff in X	(Diff in X)^2	Y - Coordinate GPS	Y - Coordinate 2 Inch aerial	Diff in Y	(Diff in Y)^2	(Diff in X)^2+ (Diff in Y)^2	
38	(D) S. 5th St, next to Pizza Hut	4891370.670	4891370.725	-0.055	0.003	3469430.490	3469432.067	-1.577	2.486	2.489	
40	(S) Kellogg Ave & S. 2nd St	4890347.630	4890347.275	0.355	0.126	3470915.720	3470914.907	0.813	0.661	0.787	
42	(D) Grand Ave & 7th St	4888541.310	4888541.346	-0.036	0.001	3473225.620	3473225.805	-0.184	0.034	0.035	
44	(S) Murray Dr & Roosevelt Ave	4887878.560	4887878.069	0.491	0.241	3477403.660	3477404.718	-1.058	1.119	1.360	
55	(D) On Access road to Hilton Coliseum	4885153.290	4885153.318	-0.028	0.001	3470286.340	3470286.373	-0.033	0.001	0.002	
								Sum		22.608	ft
								Average		0.870	ft
								RMSE		0.932	ft
								NSSDA		1.614	ft

D = Drainage Structure

A = Access Road

S = Side Walk intersection

Notes:
A circle of 0.93 ft radius defines horizontal RMSE
Positional Accuracy: Tested 1.61 ft horizontal accuracy at 95% confidence interval
(This means that the user of this data set can be confident that the horizontal position of a well-defined feature will be with in 1.61 ft of its true location, as best as its true location has been determined 95% of the time.)

Table A.3: Positional Accuracy for 6-inch resolution aerial photograph

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+ (Diff in Y)2
		GPS	6 Inch aerial			GPS	6 Inch aerial			
1	(D) Airport Road, Near to Sams club Parking Lot	4890581.180	4890579.487	1.693	2.866	3463500.760	3463501.003	-0.243	0.059	2.925
2	(S) Airport Road & S. Duff X. NW Side Walk	4891232.530	4891230.999	1.531	2.343	3463496.960	3463497.476	-0.516	0.267	2.609
3	(A) S. 17th Street	4890381.980	4890380.039	1.941	3.769	3465417.980	3465417.984	-0.004	0.000	3.769
4	(S) S. Duff. Near to US 30 E Ramp	4891644.850	4891642.515	2.335	5.452	3464219.960	3464220.974	-1.014	1.028	6.481
5	(S) S. 16th Street & Buckeye Road	4890919.140	4890917.011	2.129	4.533	3466165.190	3466165.493	-0.303	0.092	4.625
6	(D) S. 16th Street West, Away from the intersection	4892018.840	4892016.971	1.869	3.493	3466132.550	3466132.952	-0.402	0.162	3.655
7	(D) Near to K-Mart Parking Lot on Buckeye	4890955.890	4890953.516	2.374	5.637	3466790.710	3466790.997	-0.287	0.082	5.720
8	(D) On Buckeye, to the end, near Red Lobster	4890951.020	4890949.006	2.014	4.055	3467603.500	3467603.527	-0.027	0.001	4.056
9	(S) S. Duff Ave, Near to Happy Joes	4891223.620	4891221.457	2.163	4.679	3468784.650	3468784.551	0.100	0.010	4.689
10	(S) S. Duff Ave, near to Honda	4891320.050	4891317.038	3.013	9.075	3468940.300	3468939.990	0.310	0.096	9.171
11	(S) Bus Stop near to River Breach Apt	4890755.990	4890753.955	2.035	4.140	3469431.740	3469432.503	-0.763	0.582	4.721
12	(S) Side Walk on S. Duff Ave near to Arby's	4891209.690	4891207.958	1.732	3.001	3469866.100	3469866.474	-0.374	0.140	3.141
13	(S) Sherman Ave & S. 2nd St	4890755.570	4890753.482	2.088	4.359	3470978.680	3470978.999	-0.319	0.102	4.461
14	(S) Sherman Ave & Lincoln Way	4890755.490	4890753.019	2.471	6.107	3471377.860	3471378.483	-0.623	0.388	6.495
15	(S) Kellogg Ave, Next to Parking Lot	4890392.280	4890389.534	2.746	7.541	3472008.400	3472009.023	-0.623	0.389	7.930
16	(S) Duff Ave, Near to RR Tracks	4891210.590	4891208.937	1.653	2.732	3472095.160	3472095.959	-0.799	0.639	3.371
17	(D) Lincoln Way & Grand Ave, Near H-Video	4888629.180	4888627.306	1.874	3.511	3471477.110	3471478.231	-1.121	1.256	4.767
18	(S) Lincoln Way & Grand Ave, Near Credit Union	4888468.360	4888466.496	1.864	3.475	3471472.060	3471473.148	-1.088	1.184	4.659
19	(S) Bus Stop on 5th St, near to City Hall	4889173.260	4889171.022	2.238	5.010	3472511.550	3472512.513	-0.963	0.927	5.937
20	(S) Grand Ave & 5th St	4888634.410	4888632.037	2.373	5.631	3472438.350	3472438.957	-0.607	0.368	5.999
21	(S) Wilson Ave & 8th St	4889064.870	4889062.526	2.344	5.497	3473614.390	3473615.038	-0.648	0.420	5.916
22	(S) Hodge Ave & 8th St	4888238.080	4888236.992	1.088	1.184	3473592.320	3473593.978	-1.658	2.750	3.933
23	(S) Grand Ave & 9th St	4888539.530	4888537.003	2.527	6.386	3474108.680	3474109.542	-0.861	0.742	7.128
24	(S) Grand Ave & 11th St	4888589.330	4888587.033	2.297	5.278	3474738.240	3474739.494	-1.254	1.573	6.851

Table A.3: (continued)

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+
		GPS	6 Inch aerial			GPS	6 Inch aerial			(Diff in Y)2
25	(S) Clark Ave & 13th St	4889461.810	4889459.989	1.821	3.316	3475654.620	3475654.549	0.072	0.005	3.322
26	(S) Harding Ave & 13th St	4888267.510	4888264.476	3.034	9.206	3475689.900	3475690.112	-0.212	0.045	9.251
27	(S) Wilson Ave & 16th St	4889021.470	4889019.982	1.488	2.215	3477059.490	3477059.525	-0.035	0.001	2.216
28	(S) Harding Ave & 16th St	4888265.630	4888263.524	2.106	4.436	3477008.060	3477008.545	-0.485	0.235	4.671
29	(S) Duff Ave & Jenson Ave	4889025.730	4889023.473	2.257	5.093	3481760.110	3481761.007	-0.897	0.804	5.898
30	(S) Bus Stop near Wall-mart parking lot	4888317.410	4888315.459	1.952	3.808	3481754.210	3481756.021	-1.811	3.278	7.087
31	(A) Access road on 28th St, next to Grand Ave	4888603.690	4888601.514	2.176	4.736	3481036.940	3481037.984	-1.044	1.090	5.826
32	(S) 30th St & Ferndale Ave	4887439.790	4887437.482	2.308	5.327	3481673.140	3481674.482	-1.342	1.800	7.127
33	(S) Side Walk next to Hilton Coliseum, East End	4884890.320	4884887.954	2.366	5.600	3470796.820	3470796.056	0.764	0.583	6.183
34	(S) Lincoln Way, near to Hazel Ave	4886731.970	4886729.480	2.490	6.202	3471371.320	3471371.503	-0.183	0.033	6.235
35	(S) Lincoln Way & Hazel Ave	4886824.480	4886821.999	2.481	6.156	3471432.490	3471432.989	-0.498	0.249	6.405
36	(A) Access road from house to Lincoln Way	4886492.020	4886490.511	1.509	2.276	3471365.000	3471366.010	-1.010	1.020	3.296
37	(S) End Side Walk near to Happy Joes	4891225.180	4891223.970	1.210	1.465	3468607.630	3468607.529	0.101	0.010	1.475
38	(D) S. 5th St, next to Pizza Hut	4891370.670	4891368.504	2.166	4.690	3469430.490	3469430.560	-0.070	0.005	4.695
39	(S) S. 3rd St, next to parking lot	4890988.610	4890986.510	2.100	4.409	3470449.740	3470449.429	0.311	0.097	4.506
40	(S) Kellogg Ave & S. 2nd St	4890347.630	4890345.025	2.605	6.784	3470915.720	3470916.461	-0.741	0.549	7.333
41	(S) Next to parking lot on Main St	4889145.720	4889143.024	2.696	7.268	3472157.500	3472158.036	-0.536	0.287	7.555
42	(D) Grand Ave & 7th St	4888541.310	4888539.979	1.331	1.773	3473225.620	3473225.991	-0.371	0.138	1.911
43	(S) Grand Ave & 12th St	4888516.690	4888514.997	1.693	2.865	3475226.860	3475227.522	-0.662	0.438	3.303
44	(S) Murray Dr & Roosevelt Ave	4887878.560	4887876.939	1.621	2.629	3477403.660	3477404.573	-0.913	0.833	3.462
45	(S) Murray Dr & Northwestern Ave	4887109.140	4887106.529	2.611	6.816	3477394.150	3477394.977	-0.827	0.683	7.499
46	(S) Clark Ave & 18th St	4889460.500	4889458.009	2.491	6.207	3477760.320	3477760.988	-0.668	0.446	6.654
47	(D) Clark Ave & 9th ST	4889425.260	4889423.031	2.229	4.969	3474084.260	3474084.954	-0.694	0.482	5.451
48	(D) 6th St & Northwestern Ave	4887992.070	4887990.468	1.602	2.567	3472807.050	3472807.530	-0.480	0.230	2.797

Table A.3: (continued)

Point ID	Point Description	X - Coordinate GPS	X - Coordinate 6 Inch aerial	Diff in X	(Diff in X)^2	Y - Coordinate GPS	Y - Coordinate 6 Inch aerial	Diff in Y	(Diff in Y)^2	(Diff in X)^2+ (Diff in Y)2
49	(S) Bus Stop near to ISU Credit Union, Opp DOT	4887983.060	4887980.588	2.472	6.113	3471439.240	3471440.456	-1.216	1.479	7.592
50	(S) Clark Ave & 6th St, Near to City Hall	4889439.370	4889437.482	1.888	3.564	3472807.450	3472808.471	-1.021	1.043	4.607
51	(D) S. 3rd St & Kellogg Ave	4890339.160	4890337.519	1.641	2.694	3470445.430	3470446.010	-0.579	0.336	3.030
52	(D) On Airport Rd, next to SAM's Parking lot	4890272.010	4890270.534	1.476	2.180	3463496.700	3463496.981	-0.281	0.079	2.259
53	(D) On S. 16th St next to K-Mart parking lot	4890599.470	4890597.476	1.994	3.977	3466146.060	3466146.527	-0.467	0.218	4.196
54	(D) On Grand Ave, next to First National Bank	4888546.850	4888544.519	2.331	5.436	3480010.180	3480010.964	-0.784	0.615	6.051
55	(D) On Access road to Hilton Coliseum	4885153.290	4885151.913	1.377	1.897	3470286.340	3470287.497	-1.157	1.339	3.236

Sum	278.136	ft
Average	5.057	ft
RMSE	2.249	ft
NSSDA	3.892	ft

D = Drainage Structure
A = Access Road
S = Side Walk intersection

Notes:
A circle of 2.25 ft radius defines horizontal RMSE
Positional Accuracy: Tested 3.89 ft horizontal accuracy at 95% confidence interval
(This means that the user of this data set can be confident that the horizontal position of a well-defined feature will be with in 3.89 ft of its true location, as best as its true location has been determined 95% of the time.)

Table A.4: Positional Accuracy for 24-inch resolution aerial photograph

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+ (Diff in Y)2
		GPS	24 Inch aerial			GPS	24 Inch aerial			
3	(A) S. 17th Street	4890381.980	4890384.108	-2.128	4.528	3465417.980	3465415.905	2.075	4.306	8.834
4	(S) S. Duff. Near to US 30 E Ramp	4891644.850	4891644.155	0.695	0.483	3464219.960	3464217.926	2.034	4.137	4.620
5	(S) S. 16th Street & Buckeye Road	4890919.140	4890918.210	0.930	0.865	3466165.190	3466164.084	1.106	1.223	2.088
9	(S) S. Duff Ave, Near to Happy Joes	4891223.620	4891224.181	-0.561	0.315	3468784.650	3468786.101	-1.451	2.105	2.420
10	(S) S. Duff Ave, near to Honda	4891320.050	4891319.921	0.129	0.017	3468940.300	3468938.173	2.127	4.524	4.541
11	(S) Bus Stop near to River Breach Apt	4890755.990	4890755.998	-0.008	0.000	3469431.740	3469429.953	1.787	3.193	3.193
12	(S) Side Walk on S. Duff Ave near to Arby's	4891209.690	4891208.102	1.588	2.522	3469866.100	3469866.049	0.051	0.003	2.524
13	(S) Sherman Ave & S. 2nd St	4890755.570	4890753.992	1.578	2.490	3470978.680	3470978.058	0.622	0.387	2.877
14	(S) Sherman Ave & Lincoln Way	4890755.490	4890758.045	-2.555	6.528	3471377.860	3471374.143	3.717	13.816	20.344
15	(S) Kellogg Ave, Next to Parking Lot	4890392.280	4890394.033	-1.753	3.073	3472008.400	3472010.013	-1.613	2.602	5.675
16	(S) Duff Ave, Near to RR Tracks	4891210.590	4891210.076	0.514	0.264	3472095.160	3472091.908	3.252	10.576	10.840
18	(S) Lincoln Way & Grand Ave, Near Credit Union	4888468.360	4888467.161	1.199	1.438	3471472.060	3471471.963	0.097	0.009	1.447
19	(S) Bus Stop on 5th St, near to City Hall	4889173.260	4889175.944	-2.684	7.204	3472511.550	3472508.019	3.531	12.468	19.672
20	(S) Grand Ave & 5th St	4888634.410	4888636.175	-1.765	3.115	3472438.350	3472435.951	2.399	5.755	8.870
21	(S) Wilson Ave & 8th St	4889064.870	4889064.003	0.867	0.752	3473614.390	3473613.978	0.412	0.170	0.921
22	(S) Hodge Ave & 8th St	4888238.080	4888233.959	4.121	16.983	3473592.320	3473588.021	4.299	18.481	35.464
24	(S) Grand Ave & 11th St	4888589.330	4888588.046	1.284	1.649	3474738.240	3474738.057	0.183	0.033	1.682
25	(S) Clark Ave & 13th St	4889461.810	4889457.994	3.816	14.562	3475654.620	3475654.051	0.569	0.324	14.886
26	(S) Harding Ave & 13th St	4888267.510	4888269.960	-2.450	6.003	3475689.900	3475692.021	-2.121	4.499	10.501
27	(S) Wilson Ave & 16th St	4889021.470	4889018.159	3.311	10.963	3477059.490	3477059.994	-0.504	0.254	11.217
28	(S) Harding Ave & 16th St	4888265.630	4888268.037	-2.407	5.794	3477008.060	3477010.013	-1.953	3.814	9.608
29	(S) Duff Ave & Jenson Ave	4889025.730	4889022.120	3.610	13.032	3481760.110	3481762.114	-2.004	4.016	17.048
32	(S) 30th St & Ferndale Ave	4887439.790	4887442.079	-2.289	5.240	3481673.140	3481671.995	1.145	1.311	6.551
33	(S) Side Walk next to Hilton Coliseum, East End	4884890.320	4884888.035	2.285	5.221	3470796.820	3470796.010	0.810	0.656	5.877

Table A.4: (continued)

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+ (Diff in Y)2
		GPS	24 Inch aerial			GPS	24 Inch aerial			
34	(S) Lincoln Way, near to Hazel Ave	4886731.970	4886732.083	-0.113	0.013	3471371.320	3471370.098	1.222	1.493	1.506
35	(S) Lincoln Way & Hazel Ave	4886824.480	4886823.991	0.489	0.239	3471432.490	3471436.060	-3.570	12.745	12.984
36	(A) Access road from house to Lincoln Way	4886492.020	4886490.036	1.984	3.936	3471365.000	3471363.975	1.025	1.051	4.987
37	(S) End Side Walk near to Happy Joes	4891225.180	4891225.947	-0.767	0.588	3468607.630	3468605.987	1.643	2.699	3.288
39	(S) S. 3rd St, next to parking lot	4890988.610	4890988.086	0.524	0.275	3470449.740	3470450.010	-0.270	0.073	0.347
40	(S) Kellogg Ave & S. 2nd St	4890347.630	4890348.169	-0.539	0.291	3470915.720	3470911.941	3.779	14.281	14.571
41	(S) Next to parking lot on Main St	4889145.720	4889152.191	-6.471	41.874	3472157.500	3472156.110	1.390	1.932	43.806
43	(S) Grand Ave & 12th St	4888516.690	4888517.981	-1.291	1.667	3475226.860	3475230.044	-3.184	10.138	11.805
44	(S) Murray Dr & Roosevelt Ave	4887878.560	4887878.032	0.528	0.279	3477403.660	3477406.096	-2.436	5.934	6.213
45	(S) Murray Dr & Northwestern Ave	4887109.140	4887112.129	-2.989	8.934	3477394.150	3477396.048	-1.898	3.602	12.537
46	(S) Clark Ave & 18th St	4889460.500	4889460.027	0.473	0.224	3477760.320	3477761.989	-1.669	2.786	3.009
49	(S) Bus Stop near to ISU Credit Union, Opp DOT	4887983.060	4887984.051	-0.991	0.982	3471439.240	3471439.966	-0.726	0.527	1.509
50	(S) Clark Ave & 6th St, Near to City Hall	4889439.370	4889440.184	-0.814	0.663	3472807.450	3472803.929	3.521	12.397	13.060

Sum	341.323	ft
Average	9.225	ft
RMSE	3.037	ft
NSSDA	5.257	ft

D = Drainage Structure
A = Access Road
S = Side Walk intersection

Notes:
A circle of 3.04 ft radius defines horizontal RMSE
Positional Accuracy: Tested 5.26 ft horizontal accuracy at 95% confidence interval
(This means that the user of this data set can be confident that the horizontal position of a well-defined feature will be with in 3.89 ft of its true location, as best as its true location has been determined 95% of the time.)

Table A.5: Positional Accuracy for 1-meter resolution aerial photograph

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+
		GPS	1-m aerial			GPS	1-m aerial			(Diff in Y)2
4	(S) S. Duff. Near to US 30 E Ramp	449573.192	449573.523	-0.331	0.109	4650307.519	4650305.426	2.093	4.382	4.492
10	(S) S. Duff Ave, near to Honda	449482.609	449481.495	1.114	1.241	4651746.287	4651746.466	-0.179	0.032	1.273
12	(S) Side Walk on S. Duff Ave near to Arby's	449450.627	449451.513	-0.886	0.784	4652028.556	4652026.458	2.098	4.402	5.186
13	(S) Sherman Ave & S. 2nd St	449314.241	449313.482	0.759	0.577	4652368.344	4652368.506	-0.162	0.026	0.603
15	(S) Kellogg Ave, Next to Parking Lot	449205.381	449205.478	-0.097	0.009	4652682.724	4652682.480	0.244	0.060	0.069
16	(S) Duff Ave, Near to RR Tracks	449454.858	449452.470	2.388	5.703	4652707.706	4652705.470	2.236	4.998	10.701
19	(S) Bus Stop on 5th St, near to City Hall	448834.862	448831.508	3.354	11.250	4652838.188	4652838.503	-0.315	0.099	11.349
20	(S) Grand Ave & 5th St	448670.555	448669.489	1.066	1.137	4652816.842	4652814.489	2.353	5.536	6.673
21	(S) Wilson Ave & 8th St	448803.795	448804.491	-0.696	0.485	4653174.395	4653174.440	-0.045	0.002	0.487
22	(S) Hodge Ave & 8th St	448551.849	448549.468	2.381	5.668	4653169.138	4653168.450	0.688	0.473	6.142
25	(S) Clark Ave & 13th St	448928.357	448927.546	0.811	0.658	4653795.310	4653794.516	0.794	0.631	1.289
26	(S) Harding Ave & 13th St	448564.538	448564.503	0.035	0.001	4653808.180	4653809.490	-1.310	1.716	1.717
27	(S) Wilson Ave & 16th St	448796.688	448795.466	1.222	1.493	4654224.130	4654224.446	-0.316	0.100	1.592
28	(S) Harding Ave & 16th St	448566.306	448565.477	0.829	0.687	4654209.802	4654210.470	-0.668	0.447	1.134
29	(S) Duff Ave & Jenson Ave	448806.332	448804.532	1.800	3.240	4655656.318	4655656.527	-0.209	0.044	3.284
31	(A) Access road on 28th St, next to Grand Ave	448676.460	448676.503	-0.043	0.002	4655436.730	4655435.483	1.247	1.556	1.558
32	(S) 30th St & Ferndale Ave	448322.970	448321.474	1.496	2.237	4655632.636	4655632.528	0.108	0.012	2.249
35	(S) Lincoln Way & Hazel Ave	448117.318	448116.490	0.828	0.685	4652513.587	4652515.501	-1.914	3.663	4.348
39	(S) S. 3rd St, next to parking lot	449384.305	449384.463	-0.158	0.025	4652206.772	4652206.512	0.260	0.068	0.093
40	(S) Kellogg Ave & S. 2nd St	449189.838	449190.522	-0.684	0.467	4652349.885	4652347.504	2.381	5.669	6.136
43	(S) Grand Ave & 12th St	448639.637	448637.496	2.141	4.583	4653666.658	4653665.466	1.192	1.420	6.003
44	(S) Murray Dr & Roosevelt Ave	448449.075	448446.553	2.522	6.361	4654331.022	4654331.542	-0.520	0.271	6.632
45	(S) Murray Dr & Northwestern Ave	448214.629	448214.462	0.167	0.028	4654329.490	4654330.442	-0.952	0.906	0.934
46	(S) Clark Ave & 18th St	448931.696	448932.567	-0.871	0.758	4654436.881	4654436.464	0.417	0.174	0.931

Table A.5: (continued)

Point ID	Point Description	X - Coordinate		Diff in X	(Diff in X)^2	Y - Coordinate		Diff in Y	(Diff in Y)^2	(Diff in X)^2+
		GPS	1-m aerial			GPS	1-m aerial			(Diff in Y)2
50	(S) Clark Ave & 6th St, Near to City Hall	448916.466	448915.501	0.965	0.931	4652927.871	4652925.477	2.394	5.733	6.663

Sum	91.539	m
Average	3.662	m
Average	11.984	ft
RMSE	1.914	m
RMSE	6.263	ft
NSSDA	3.312	m
NSSDA	10.840	ft

D = Drainage Structure
A = Access Road
S = Side Walk intersection

Notes:
A circle of 3.46 ft radius defines horizontal RMSE
Positional Accuracy: Tested 5.99 ft horizontal accuracy at 95% confidence interval
(This means that the user of this data set can be confident that the horizontal position of a well-defined feature will be with in 5.99 ft of its true location, as best as its true location has been determined 95% of the time.)

APPENDIX B: DESCRIPTION OF FROM/TO LOCATIONS FOR PILOT STUDY 2

AS 1151 (State Avenue): Begin at southern end at the intersection of State Ave. and Oakwood Drive. Continue north to south expansion joint on bridge over US 30.

AS 1165 (Union): Begin as west end at the intersection of Union Drive and Hyland Avenue. Continue east on Union Drive to the intersection of Welch Ave. and Lincoln Way. End at the center of the median on the west side of the intersection.

AS 1178 (Todd Drive): Begin at west end in circle of Todd Drive. Proceed east on Todd Drive to Abraham Drive. End at intersection of Todd and Abraham Drive.

AS 1148 (Grand Avenue): Begin on South end at the intersection of Grand and Lincoln Way. Proceed north to the intersection of Grand and 13th Street.

AS 1210 (Duff): Begin at south end at the end of the median just north of SE 16th Street. Go north to the intersection of Lincoln Way and Duff (US 69). The raised concrete gore nose is the begin point.

AS 1152 (Dartmoor Road): Begin at west end at the intersection of 510th Avenue and Dartmoor Road. Continue east to the intersection of Dartmoor road with State Avenue.

All measurements involving intersections start or end at the centerline of the road unless a median is present. In that case they end at the center of the south or west median.

APPENDIX C: TABLES SHOWING LINEAR OFFSET DIFFERENCES BETWEEN 6-INCH BASELINE AND GIMS CARTOGRAPHY

Table C.1: Difference Between Linear Offset to Intermediate Intersections For Airport Road

Datum			GIMS		
ID	Segment Length (feet)	Linear Offset to Intersection (feet)	Segment Length (feet)	Linear Offset to Intersection (feet)	Datum Offset Minus Cartography (feet)
1	13854.2	2640.6	13921.8	2625.7	14.9
2	13854.2	3300.1	13921.8	3319.0	-18.9
3	13854.2	3965.1	13921.8	3987.2	-22.1
4	13854.2	5292.3	13921.8	5287.5	4.8
5	13854.2	6220.5	13921.8	6248.1	-27.6
6	13854.2	7412.0	13921.8	7428.7	-16.7
7	13854.2	8523.1	13921.8	8525.7	-2.6

Table C.2: Difference Between Linear Offset to Intermediate Intersections For K Avenue

Datum			GIMS		
ID	Segment Length (feet)	Linear Offset to Intersection (feet)	Segment Length (feet)	Linear Offset to Intersection (feet)	Datum Offset Minus Cartography (feet)
1	5197.1	365.9	5189.9	368.5	-2.6
2	5197.1	735.9	5189.9	739.0	-3.1
3	5197.1	1105.9	5189.9	1095.1	10.9
4	5197.1	1476.0	5189.9	1479.1	-3.1
5	5197.1	1837.7	5189.9	1833.1	4.6
6	5197.1	2218.1	5189.9	2200.5	17.6
7	5197.1	2588.2	5189.9	2581.4	6.7
8	5197.1	2959.2	5189.9	2953.0	6.2
9	5197.1	3329.3	5189.9	3327.7	1.5
10	5197.1	3700.3	5189.9	3694.2	6.2
11	5197.1	4156.7	5189.9	4154.0	2.7
12	5197.1	4526.7	5189.9	4525.6	1.1

Table C.3: Difference Between Linear Offset to Intermediate Intersections For L Avenue

Datum			GIMS		Datum Offset Minus Cartography (feet)
ID	Segment Length (feet)	Linear Offset to Intersection (feet)	Linear Offset to Intersection (feet)	Linear Offset to Intersection (feet)	
1	6208.2	599.7	6213.2	620.1	-20.4
2	6208.2	1009.5	6213.2	1016.5	-7.0
3	6208.2	1375.7	6213.2	1399.2	-23.5
4	6208.2	1745.8	6213.2	1770.8	-25.0
5	6208.2	2115.8	6213.2	2119.9	-4.2
6	6208.2	2485.8	6213.2	2510.1	-24.3
7	6208.2	2845.9	6213.2	2858.1	-12.2
8	6208.2	3227.0	6213.2	3228.4	-1.3
9	6208.2	3597.1	6213.2	3611.1	-14.0
10	6208.2	3968.3	6213.2	3986.4	-18.1
11	6208.2	4339.6	6213.2	4350.5	-10.9
12	6208.2	4708.3	6213.2	4717.0	-8.7
13	6208.2	5166.5	6213.2	5180.5	-14.0
14	6208.2	5536.5	6213.2	5544.6	-8.1

Table C.4: Difference Between Linear Offset to Intermediate Intersections For Todd Drive

	Datum		GIMS		
ID	Segment Length (feet)	Linear Offset to Intersection (feet)	Segment Length (feet)	Linear Offset to Intersection (feet)	Datum Offset Minus Cartography (feet)
1	4860.5	247.9	4787.7	236.5	11.4
2	4860.5	1496.1	4787.7	1452.6	43.5
3	4860.5	2082.2	4787.7	2043.4	38.8
4	4860.5	2591.6	4787.7	2560.5	31.1
5	4860.5	2384.6	4787.7	2360.3	24.2
6	4860.5	2920.2	4787.7	2865.0	55.2
7	4860.5	3195.3	4787.7	*No intersection in cartography*	
8	4860.5	3556.9	4787.7	3514.2	42.7
9	4860.5	3939.9	4787.7	3896.2	43.7
10	4860.5	4199.5	4787.7	4147.1	52.3
11	4860.5	4533.9	4787.7	4469.8	64.1

Table C.5: Difference Between Linear Offset to Intermediate Intersections For Union

ID	Datum		GIMS		Datum Offset Minus Cartography (feet)
	Segment Length (feet)	Linear Offset to Intersection (feet)	Segment Length (feet)	Linear Offset to Intersection (feet)	
1	7358.8	153.1	7257.9	119.0	34.0
2	7358.8	528.4	7257.9	519.7	8.7
3	7358.8	894.8	7257.9	882.6	12.3
4	7358.8	1548.3	7257.9	1515.5	32.8
5	7358.8	1798.5	7257.9	1808.7	-10.2
6	7358.8	2453.4	7257.9	2460.4	-7.0
7	7358.8	3224.6	7257.9	3208.0	16.6
8	7358.8	4150.4	7257.9	4119.6	30.8
9	7358.8	5102.6	7257.9	5051.5	51.1
10	7358.8	5466.1	7257.9	5424.6	41.5
11	7358.8	6693.6	7257.9	6627.9	65.6
12	7358.8	7096.8	7257.9	7032.9	63.9