Evaluating Remotely Sensed Images for Use in Inventorying Roadway Infrastructure Features

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University of California, Santa Barbara

Center for Transportation Research and Education

Iowa State University

Final Report • May 2001

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EVALUATING REMOTELY SENSED IMAGES FOR USE IN INVENTORYING ROADWAY INFRASTRUCTURE FEATURES

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May 2001

INTRODUCTION

In order to effectively manage and maintain the nation's transportation infrastructure, accurate inventory and condition data are required. Up-to-date information helps to identify safety or operationally deficient elements, prioritize maintenance needs, and monitor conditions (Opiela and Perkins, 1986*)*. As a result, all Departments of Transportation (DOTs) in the United States maintain some type of roadway feature inventory (Karimi et al., 2000). Roadway inventory data are used by DOTs for a variety of purposes including traffic safety, construction projects, traffic engineering studies, evaluation of maintenance needs, and planning. Inventory data are also collected and maintained to meet Federal data reporting requirements. Infrastructure data are used by the Federal Highway Administration (FHWA) as informational support for the "Condition and Performance Report" to Congress, as well as data that appears in various FHWA publications. Inventory data are also used by other agencies including other state and local agencies, business and industry, educational institutions, the media, and the general public (FHWA, 2000).

Inventory data are necessary to support the numerous functions within DOTs and state and local transportation agencies that utilize those data. However, most data collection methods, which include manual methods, global positioning systems (GPS), and video or photolog vans, are conducted in the field requiring significant time and resources to cover even a minor amount of roadway. This is problematic since both state DOTs and local areas are responsible for significant street network systems. Iowa, for example, has a surface street system covering approximately 110,000 linear miles. As a result, resource constraints often dictate that only minimal inventory data elements, such as pavement condition or number of lanes, are collected and reported systemwide. Other data are collected at the corridor level as needed for specific uses such as planning of new construction or evaluation of high accident locations. To meet data and reporting needs, sampling of subsets of roadway segments are often used and then extrapolated to provide systemwide estimates.

While sampling may provide adequate information for some uses, other types of applications or analyses are limited by the inability to cost-effectively collect comprehensive data. Traffic studies, safety studies, and evaluation of access control require more comprehensive data than is provided by sampling. Safety studies in particular could benefit from more data. Many aspects of the roadway have been correlated to occurrence of accidents. For example, a narrow bridge width to approaching roadway width ratio has been associated with increase in accident (Fitzpatrick et al., 2000). Other roadway features such as lane width, shoulder width, and location of utility poles or other fixed objects along the roadway influence likelihood and severity of accidents. However, even with crash data that has been accurately spatially located, it is almost impossible to evaluate roadway deficiencies without a supporting database of roadway information.

RESEARCH OBJECTIVES AND SCOPE OF WORK

The main objective of this research was to evaluate the use of remotely sensed images as a method to facilitate accurate and rapid collection of large quantities of inventory data. Images collected from either an airplane or satellite can be collected fairly rapidly for large areas without locating on-road or interfering with traffic. With the launching of the IKONOS satellite, resolutions of 1 meter can be practically obtained from space. Image resolution of as high as 1-inch are possible with aerial photography. Aircraft can be flown at higher altitudes for lower resolutions. Since cost typically decreases as resolution decreases, one of the goals of the research was to test images at different levels of resolution to make recommendations on the minimum necessary to collect specific inventory features. This is especially important since many agencies already have access to low resolution images such as the USGS orthophoto quarter quads. Besides the advantage of more rapid data collection, use of remote sensing may allow collection of data which was previously difficult to obtain from conventional methods.

The accomplish the objectives stated, the scope of research included the following:

1) Identify inventory elements currently collected by transportation agencies or those that agencies are considering.
2) Identify current methodologies for inventory data collection and evaluate the advantages and disadvantages of each.
3) Conduct a pilot study to evaluate which inventory elements can be located and/or measured from aerial photographs at different resolutions.
4) Evaluate the spatial accuracy of aerial photographs at different resolutions. Make recommendations on the level of resolution necessary for collection of the specific items included in the pilot study. Such a determination would provide the information necessary for decision-makers to choose what elements could be collected and what resolution of imagery would be required to do so.
6) Evaluate the advantages and disadvantages of using remotely sensed images for data collection.

PILOT STUDY

The pilot study for this project was located along the US-69 through the city of Ames, Iowa as shown in Figure III-1. The study corridor included three roadway segments, S. Duff Avenue, Lincoln Way and Grand Avenue. The corridor was selected is part due to the availability of aerial images at different resolutions along the corridor. The corridor also had a wide variety of inventory elements. Eight intersections were located in 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. The length of the corridor segment was 4.1 miles and most of the surrounding land use was either commercial or residential.

Imagery

Four aerial photograph datasets of varying resolutions were available for the study area and were utilized in different aspects of the project. All datasets were panchromatic. The imagery datasets included:

- 2-inch resolution
- 6-inch resolution
- 24-inch resolution
- 1-meter (39.37 inch) resolution

The 1-meter images are similar to the resolution available from the IKONOS satellite. The images were used to simulate the best currently available satellite data. A more in-depth description of the datasets is provided in Appendix C.

Inventory Data Elements

A list of inventory elements tested in the research is shown in Table III-1. The data elements were selected based on those collected by the Iowa Department of Transportation and those required by the Highway Performance Monitoring System (HPMS). In order to be included in the list, several occurrences of a specific inventory element in the study area were necessary. For example, several railroad crossings would have to be present before location of railroad crossings was used as a data element. A description of the data elements required by HPMS and collected by the Iowa DOT is listed in Appendix D.

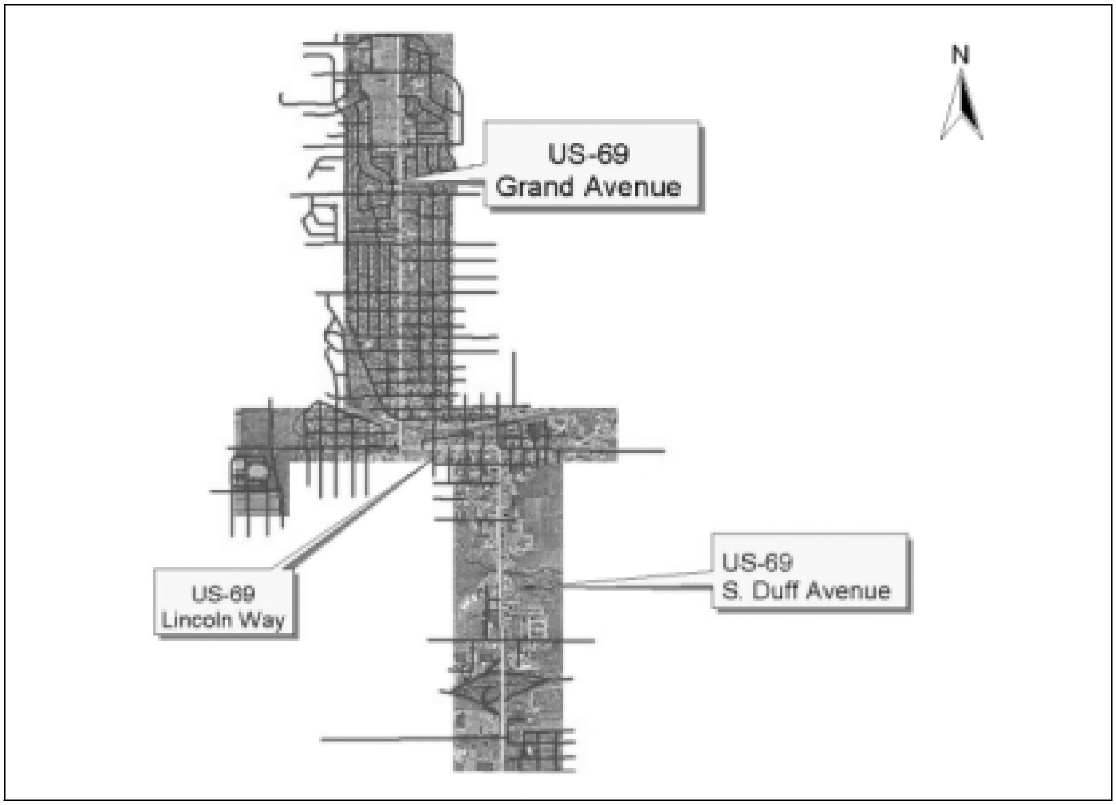

Figure III-1: US-69 Pilot Study Area Corridor

Table III-1: Pilot Study Transportation Inventory Data Elements

Data Element	Data Element	Data Element
Through lanes o Number o Width	Medians o Presence of median o Median type o Width	Right turn lane o Presence o Number o Width
	Shoulder o Presence o Type o Width	Left turn lane o Presence o Number o Width o Length
Presence of crosswalks	Location of stop bars	Presence of pedestrian islands
Access o Private access o Commercial/ industrial access	Signal o Structure o Type	On-street parking o Presence o Type of on-street parking
Pavement type	Intersection design	Total roadway width
Land use		

DATA COLLECTION

Inventory elements selected for use in the pilot study were identified, measured, and located in each dataset using ArcView GIS version 3.2. The collection of data was primarily accomplished using point and click features present in the software. Elements were identified manually and attributes of the elements, such as coordinates, populated in an attribute table using ArcView Avenue scripts. Figures III-2 and III-3 illustrate the process. A more detailed explanation of data collection is described in Appendix E. Next, a trip was made to the field to determine whether all features were properly identified and to make length and width measurements.

PERFORMANCE MEASURES

Performance measures were established to evaluate whether individual features could be identified at a given resolution and to quantify the expected accuracy of linear or positional measurements. Performance measures included:

1) Feature recognition; 2) Accuracy of linear measurements; and 3) Positional accuracy.

A more in-depth discussion of each is provided in the following sections.

Inventory Feature Recognition

Feature recognition is a measure of whether a specific inventory feature could consistently be identified in a particular dataset and was calculated using:

$$IP = (F_o/F_a) * 100$$

where:

IP = Identification Percentage (%)
F_o = # of features identified in photos
F_a = # of features identified in the field

In many cases features 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). Results are presented in Table III-2. Sample sizes for a particular inventory element may not have been consistent across datasets. The 2-inch dataset covered slightly less area than the other datasets, which may have reduced the sample size. Additionally geometric changes in the roadway had occurred at several locations between the date that the 1-meter photos were taken and the time of data collection. These locations were not included in the study resulting in fewer samples as well. As shown, most features were could be consistently identified in the 2-inch and 6-inch datasets.

Linear Measurements

Many transportation inventory elements are linear. The most distinguishing features of roadway segments, turning lanes, medians, or driveways, are length and width. Linear measurements are necessary for various applications. The length of left turn lanes is important in determining intersection capacity and storage capability. A number of

Figure III-2: Feature Identification in ArcView

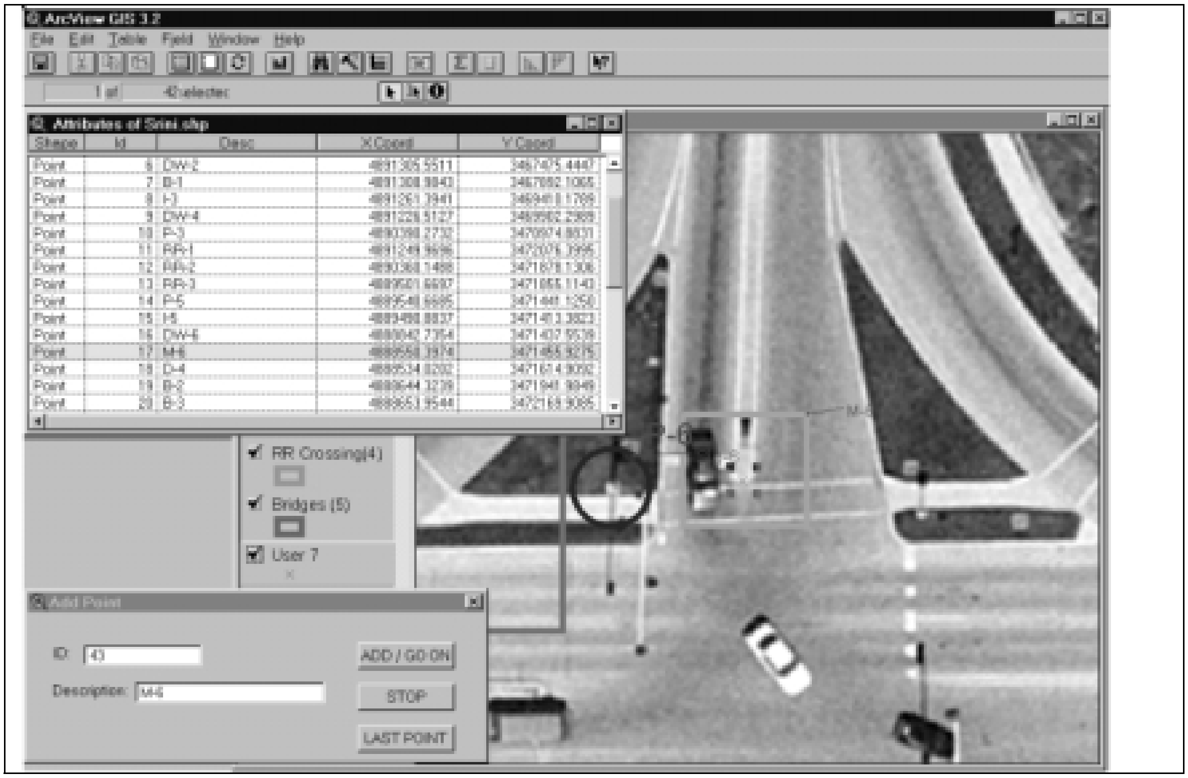

Figure III-3: Updating Attributes in ArcView

studies have suggested a correlation between lane width, shoulder width, bridge width and accident experience on rural two-lane roadways (Fitzpatrick et al., 2000; Zeeger et al, 1994; Choueiri et al, 1994). Accordingly, width measurements are necessary in evaluating accident potential. The length of passing zones on rural two-way roads has a critical impact on capacity and may also influence safety.

Although, linear measurements, such as width and length, are necessary in the various uses described as well as others, no standards for linear measurement accuracy are available. The accuracy for a particular roadway feature depends on the application and may vary from agency to agency. A capacity study may only require that the length of a roadway be measured to within ± 50 feet. A safety study may require that shoulder width be measured to within inches. NCHRP 430 (Pfefer et al, 1999) suggests the following linear accuracy measurements for collection of data for roadway features to support highway safety design decisions:

- Lane width, median width, shoulder width, width of pavement stripe, and horizontal clearance on bridge from edge of pavement to parapet or rail: ± 0.33 feet
- Lane length: ± 3.28 feet
- Length of guardrail: ± 1.64 feet

Table III-2: Feature Identification (IP > 100% indicates the feature was overestimated)

Feature	2 inch			6 inch			24 inch			1m (simulated satellite)		
	Photo	Ground	IP	Photo	Ground	IP (%)	Photo	Ground	IP (%)	Photo	Ground	IP (%)
Signs	65	68	**96**	33	68	**49**	0	68	**0**	0	68	**0**
Signals	44	44	**100**	42	44	**95**	0	44	**0**	0	44	**0**
Number 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**
Number of Lanes between Intersections	47	47	**100**	47	47	**100**	28	47	**60**	44	47	**94**
Number of Right Turn Lanes	13	13	**100**	13	13	**100**	7	13	**54**	4	7	**57**
Number of Left Turn Lanes	20	20	**100**	20	20	**100**	12	20	**60**	3	9	**33**
Number of Railroad Crossings	4	4	**100**	4	4	**100**	4	4	**100**	4	4	**100**
Number of Railroad Tracks at crossings	7	7	**100**	7	7	**100**	7	7	**100**	7	7	**100**
Number of Driveways	155	155	**100**	159	155	**103**	112	155	**72**	49	80	**61**
Number 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**
Pavement Type	19	20	**95**	11	20	**55**	0	20	**0**	0	12	**0**
Number of TWLTL	1	1	**100**	1	1	**100**	0	1	**0**	0	1	**0**
Number of separations	3	3	**100**	3	3	**100**	3	3	**100**	3	3	**100**
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 Presence	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**
Shoulders	2	2	**100**	2	2	**100**	0	2	**0**	n/a	n/a	**n/a**
Utility Poles	147	147	**100**	113	147	**77**	33	147	**22**	0	147	**0**

To evaluate the expected linear accuracy for each dataset, measurements of through lane widths, turn lane widths and lengths, median widths, and total roadway width for locations in the study area were made in the field and compared with those from the imagery. Field measurements were made using a handheld distance-measuring wheel (accuracy ± 0.1 feet). The differences between the expected (field) and observed (photo) lengths for a specific feature were recorded and the *t*-test performed to estimate the 95% confidence intervals. A description of the statistic is given in Appendix F.

Results are shown in Tables III-3 to III-6. The sample size and upper and lower bounds for the 95% confidence intervals are presented as well as mean and standard deviation. In the 2-inch and 6-inch datasets, pavement markings and vegetation, which often delineate the various elements, were more readily visible resulting in larger sample sizes. Larger sample sizes allowed more accurate error ranges to be computed. The reader is urged to interpret the error ranges generated for smaller sample sizes (≤10) with caution. Shoulder widths were also analyzed but were omitted due to limited sample size (2).

As demonstrated by Tables III-3 to III-4, lower resolution imagery does not perform nearly as well as the higher resolution datasets. Measurement of roadway linear features, such as the length of turning lane, relies on indicators, such as pavement markings or presence of vegetation, to delineate the beginning and end of a feature. Sample sizes were reduced in part to the inability to distinguish these indicators in the lower resolution images. In many cases, the 1-meter dataset ended up with less than 5 samples. Differences in samples sizes between datasets were also discussed under feature identification.

Whether the linear measurements for a particular dataset are adequate again depends on the application. Only the 2-inch dataset consistently yielded the accuracy required for collection of data for roadway features to support highway safety design decisions (from NCHRP 430). It should also be noted that length measurements were highly dependent on the ability to identify begin and end points of features.

POSITIONAL ACCURACY

A number roadway inventory features can be represented spatially as points. Features that lend themselves to representation as a point are those, which do not require spatial attributes (width, area) other than coordinates. Typical inventory features represented as points include:

- Center of intersection
- Utility poles
- Signs
- Intersection of sidewalks
- Crash location
- Center of driveways
- Drainage structures
- Anchor points for linear referencing systems

Table III-3: Linear Measurement Error Ranges for 2-Inch Dataset (not reported for sample size < 5)

Inventory Element	Accuracy for safety studies (feet)	Sample Size	95% Confidence Interval (feet)		Mean (feet)	Standard Deviation (feet)
			Lower Bound	Upper Bound		
Through Lane Width	0.33	67	-0.07	0.24	0.09	0.65
Median Width	0.33	9	-1.14	2.83	0.84	2.59
Right Turn Lane Length	3.28	12	-2.76	-0.03	-1.40	2.14
Right Turn Lane Width	0.33	12	-0.86	0.53	-0.17	1.1
Left Turn Lane Length	3.28	17	-1.24	2.68	0.72	3.82
Left Turn Lane Width	0.33	19	-0.21	0.51	0.14	0.75
Total Roadway Width	Not provided	20	-2.40	-0.28	-1.34	2.26

Table III-4: Linear Measurement Error Ranges for 6-Inch Dataset (not reported for sample size < 5)

Inventory Element	Accuracy for safety studies (feet)	Sample Size	95% Confidence Interval (feet)		Mean (feet)	Standard Deviation (feet)
			Lower Bound	Upper Bound		
Through Lane Width	0.33	67	0.01	0.38	0.19	0.78
Median Width	0.33	9	-1.75	2.57	0.41	2.81
Right Turn Lane Length	3.28	10	-2.67	6.17	1.75	6.18
Right Turn Lane Width	0.33	12	-0.32	0.90	0.29	0.95
Left Turn Lane Length	3.28	17	-3.03	4.21	0.59	7.04
Left Turn Lane Width	0.33	17	0.39	0.54	0.07	0.96
Total Roadway Width	Not provided	20	-1.51	3.49	1.00	5.34

Table III-5: Linear Measurement Error Ranges for 24-Inch Dataset (not reported for sample size < 5)

Inventory Element	Accuracy for safety studies (feet)	Sample Size	95% Confidence Interval (feet)		Mean (feet)	Standard Deviation (feet)
			Lower Bound	Upper Bound		
Through Lane Width	0.33	17	-0.61	0.37	-0.12	0.95
Median Width	0.33	5	-3.55	8.48	2.46	4.84
Right Turn Lane Length	3.28	4	Na	na	na	na
Right Turn Lane Width	0.33	6	-2.12	2.04	-0.04	1.98
Left Turn Lane Length	3.28	8	-3.97	3.00	-0.48	4.16
Left Turn Lane Width	0.33	7	-2.36	5.64	1.64	4.32
Total Roadway Width	Not provided	20	-3.56	2.96	-0.29	6.97

Table III-6: Linear Measurement Error Ranges for 1-Meter Dataset (not reported for sample size < 5)

Inventory Element	Accuracy for safety studies (feet)	Sample Size	95% Confidence Interval (feet)		Mean (feet)	Standard Deviation (feet)
			Lower Bound	Upper Bound		
Through Lane Width	0.33	6	-1.13	0.80	-0.17	0.92
Median Width, right turn lane length and width, left turn length and width, sample size < 5						
Total Roadway Width	Not provided	12	-1.34	3.04	0.85	3.45

No national standards are available for positional accuracy of roadway point features. The required accuracy for locating point features is dependent on the application. Location of signs may have lower accuracy requirements than locating accidents. NCHRP 430 (Pfefer et al, 1999) suggests the following spatial accuracy for point roadway features to support highway safety design decisions:

- Fixed objects such as signs, utility poles, light poles, etc: ± 3.28 feet
- Location of drainage structures: ± 0.33 feet
- Center of intersection: ± 3.28 feet
- Location of intersection of roadway and railroad crossings: ± 3.28 feet

The Iowa Department of Transportation is currently implementing a linear referencing system (LRS) and is in the process of selecting a methodology to create the datum for the 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 ± 3.28 feet.

Although no accuracy benchmarks are available, the National Standard for Spatial Data Accuracy (NSSDA) suggest a statistical methodology for estimating the positional accuracy of points on maps which are in digital geospatial data, with respect to georeferenced ground positions of higher accuracy (FGDC, 1998). This test applies to any georeferenced data in raster, point or vector format, which are derived from sources such as aerial photographs, satellite imagery and ground surveys. The independent source of higher accuracy can be any source whose accuracy is predefined, such as GPS survey or geodetic control survey. The NSSDA uses root-mean-square error (RMSE) to estimate positional accuracy. RMSE is the square root of average of the set of squared differences between dataset coordinate values and coordinate values from the independent source for identical points (FGDC, 1998). The accuracy is reported in ground distances at 95% confidence interval. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product. The horizontal accuracy of any data source is tested by comparing planimetric coordinates of well-defined points in the data source with that of independent source of higher accuracy. NSSDA requires minimum 20 points be tested for horizontal accuracy (FGDC, 1998). A more in-depth description of the test methodology is given in Appendix G.

Methodology for Testing Positional Accuracy

Two sets of features that could be represented as points and could reasonably be seen in all four datasets were selected to compare positional accuracy. They were the southeast corner of two intersecting sidewalks and the southeast corner of a drainage structures. A set of 55 points was located, if possible, in each of the four datasets using ArcView and coordinates added as attributes using Avenue scripts. A kinematic GPS survey was contracted for with an independent engineering consulting firm to obtain planimetric coordinates for the 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 specified in State Plane Iowa

North coordinates and NAD 1983 datum. The list of coordinate values for 55 points collected and more information on collection of GPS points are presented in Appendix H. The points from imagery were located using the same coordinate system and datum as for the reference GPS points described below.

The 2-inch, 6-inch, 24-inch and 1-meter aerial photographs were tested for horizontal positional accuracy using the root mean square test and 95% confidence interval was calculated comparing the point locations from each imagery dataset with the GPS points resulting in a measure of the error associated with each resolution of images. The GPS points were referenced with a unique id and matched to the identical point located in each of the four datasets. For the 6-inch dataset all 55 points were located and matched. In the 24-inch only 37 of the 55 points were discernible enough to be located. In the 1-meter aerial photographs only 25 points could be identified sufficiently to locate coordinates. Since the 2-inch dataset was initially only a set of scanned images, 29 of the GPS points were used to georeference the images. This left only 26 of the 55 points to test positional accuracy. Results are provided in Table III-7. As shown, even in the 1-meter datasets 95% points were located within 10.84 feet. This accuracy would be sufficient for a number of applications such as sign location.

CONCLUSIONS

The primary conclusion of this study was that the most significant difference between the datasets was the ability to visually identify various inventory features. Most features were consistently identified in the 2-inch and 6-inch datasets. A significant drop in feature identification occurred in the 24-inch and 1-meter datasets. Length measurements and the ability to spatially locate a feature were significantly influenced by whether the feature could actually be identified in the first place. As a result, the limiting factor in using lower resolution datasets was whether a feature could be identified rather than whether it could be measured accurately. However, features were identified visually in this study, the use of automated techniques such as sub-pixel analysis may improve feature identification in lower resolution imagery. Better image quality may also influence the ability to identify features.

Lane width measurement errors varied from –3.6 to 8.5 feet (95% confidence interval) among the datasets. Even in the 2-inch dataset, errors ranged from a –2.4 to

Table III-7: RMSE Values for Different Resolutions of Aerial Photographs

Aerial Resolution	RMSE (feet)	95% confidence interval (feet)
2-inch	0.93	1.61
6-inch	2.25	3.89
24-inch	3.04	5.26
1-meter	6.26	10.84

2.83 feet. Given that common lane widths are 8 to 12 feet, a measurement error of almost 3 feet would be significant. As a result, none of the images demonstrated sufficient linear accuracy to measure roadway or lanes widths, which would be used in applications such as capacity or safety studies. Length measurements errors varied from –3.97 to 6.17 feet (95% confidence interval) among the datasets. The minimum practical length for a left-turn lane (storage of approximately 5 cars) is about 100 feet. A 6-foot error is unlikely to affect capacity studies or calculation of maximum storage of left-turn lanes. As a result, all the datasets performed well for calculating length if the feature could be visually identified.

The ability to identify a feature in order to locate it spatially was much more difficult with the lower resolution datasets. However, once features were identified, they could be spatially located fairly accurately. Even in the 1-meter dataset, point locations were located within 11 feet (95% confidence interval). It is expected that this accuracy would be sufficient for locating inventory elements such as utilities, signs, sidewalks, or drainage structures, for most applications. This accuracy may not be adequate for locating features for crash analysis, however.

Lower resolution imagery does have a place in data collection; however, results of this study suggest that its' role is more limited than higher resolution imagery due to the inability to consistently identify various features. In circumstances where lower resolution data can be used, the main advantage is that it can be collected more quickly and cheaply than higher resolutions.

ADVANTAGES OF REMOTE SENSING

The main advantage of using remote sensing for collection of roadway inventory features is the reduced time for data collection compared to in-field methods such as GPS or video logging. Data collection at all resolutions resulted in a significant time savings compared to manual data collection (GPS and linear measurements in the field). Table III-8 illustrates a time comparison to collect length and width measurements in the field versus aerial photos. Figure III-4 lists the time in minutes to spatially locate and record coordinates per point for each dataset as well as time to collect in field using the kinematic GPS. The field collection times only include time to collect data once on-site. Travel times to and from the sites, as well as between sites, were not recorded. Travel time would add substantially to the time required for manual data collection, especially given the vast network roads maintained by DOTs.

Another advantage to the use of remotely sensed images for data collection is that worker do not need to be located on or near busy roadways as may be the case for field data collection methods. Even though with video/photologging, workers are located inside a vehicle, data collection must be conducted on-road, which may disrupt traffic. Aerial or satellite images also provide a permanent record. One a site is flown, the images contain all features in the area studied whether they are used at the time or not. Additional data collection only entails going back to existing images rather than making additional trips to the field. Other advantages include:

- Georeferenced or ortho-rectified images are compatible with GIS
- Data can be shared among agencies
- Multiple periods of data can be used for detection of change.

The main disadvantage of remote sensing is cost. A source at the Iowa Department of Transportation estimates that with their in-house capability to ortho-rectify aerial or satellite images, “raw” digital images can be practically obtained from a commercial vendor for approximately $100 per linear mile. Costs for ortho-rectification were not estimated since they are done in-house and no numbers were available for comparison. As shown in Table III-9, costs for collection of points using GPS exceed the costs of imagery, while collection of features using a 3-camera panoramic videologging van with GPS is similar per mile to the costs of acquiring imagery. Even so, collection of a significant amount of roadway would quickly become prohibitive for any of the methods shown. Videologging is much cheaper if a minimum of information, such as number of signs per segment, rather than location of signs or condition of sign is desired. A source at the Iowa DOT estimated that this type of videologging is approximately $11 per mile not including the initial cost to purchase the van and equipment. A description of the advantages and disadvantages of other data collection methods is provided in Appendix I.

Table III-8: Time to Measure Length and Widths for 1 Intersection (4 Approaches) by Data Collection Method

Dataset	Average data collection time for 1 intersection (minutes)		Range of data collection times for 1 intersection (minutes)	
	Imagery	Manual field data collection	Imagery	Manual field data collection
2-inch	20	33.5	13-26	25-45
6-inch	21	33.5	15-29	25-45
24-inch	21	33.5	15-30	25-45
1-meter	16	33.5	14-21	25-45

TABLE III-9: COMPARISON OF COSTS FOR DATA COLLECTION METHODS

Data Collection Method	Data Collection Area	Total Cost (not including travel time)	Cost/Mile (not including travel time)
Kinematic GPS	55 points over two miles	$1,400	$700
3-Camera panoramic videologging van with GPS	One mile	$100 (if done as part of a much larger project)	$100
6-inch aerial images	One mile	$100 (if done as part of larger project)	$100 for acquisition of photos + time in house to ortho-rectify

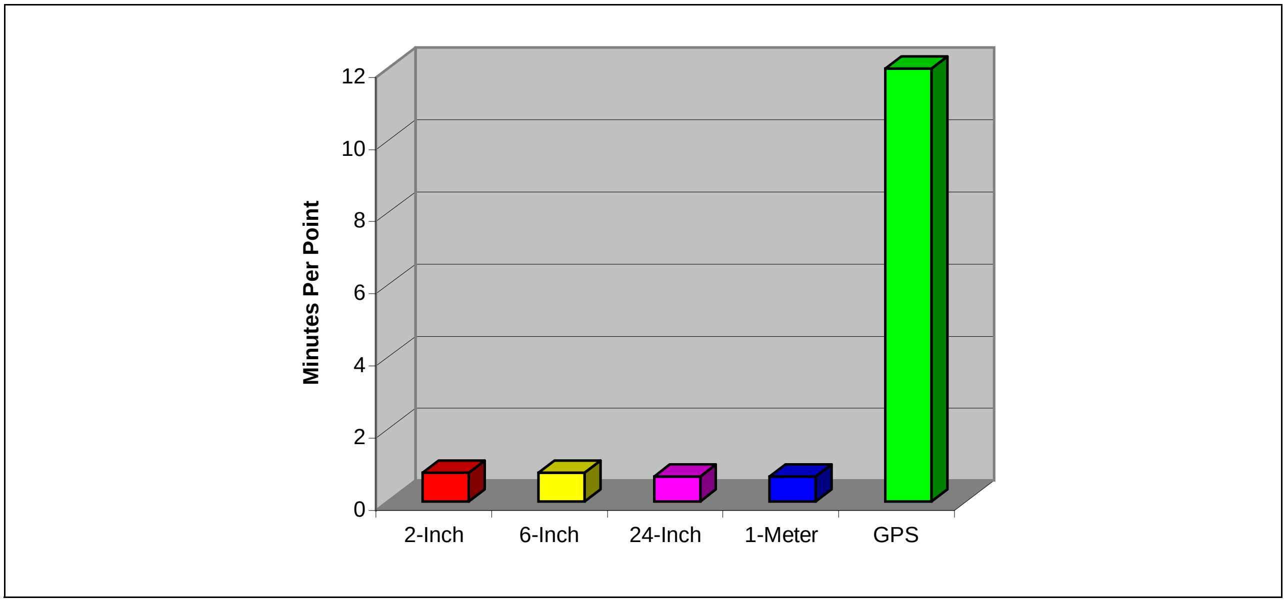

Figure III-4: Minutes per Point to Spatially Locate a Point and Record Coordinates by Data Collection Method

REFERENCES

Choueiri, Elias M., R. Lamm, J.H. Koweckner, and T. Mailaender. 1994. "Safety Aspects of Individual Design Elements and Their Interactions on Two-Lane Highways: International Perspective." Transportation Research Record 1445. Transportation Research Board, National Research Council. Washington, D.C. pp. 34-46.

Federal Geodetic Control Subcommittee, Federal Geographic Data Committee (FGDC). 1998. *Geospatial Positioning Accuracy Standards, Part 1: Reporting Methodology*. Report FGDC-STD-007.1-1998. FGDC.

Federal Highway Administration (FHWA), Office of Highway Policy Information. *Highway Performance Monitoring System Field Manual*. December 2000.

Fitzpatrick, K., K. Balke, D.W. Harwood, and I.B. Anderson. 2000. *NCHRP Report 440: Accident Mitigation Guide for Congested Rural Two-Lane Highways*. National Highway Cooperative Research Program, Transportation Research Board, National Research Council. National Academy Press. Washington, D.C. 164 pages.

Iowa DOT, 2001. Personal interview with Mr. Patrick Cain, Mr. James Majors, Ms. Karen Carroll, Office of Transportation Data, Iowa Department of Transportation, February 27, 2001.

Karimi, Hassan, Joseph E. Hummer, and Aemal J. Khattak. 2000. *National Cooperative Highway Research Program Report 437: Collection and Presentation of Roadway Inventory Data*. Transportation Research Board, National Research Council. National Academy Press. Washington, D.C. 75 pages.

Opiela, Kenneth and David D. Perkins. 1986. "Infrastructure Inventories – The Starting Point for Effective Highway Management." ITE Journal, Vol.56, No.2, February 1986. pp. 27-34.

Pfefer Ronald C., Timothy R. Neuman, and Richard A. Raub. 1999. *NCHRP Report 430:Improved Safety Information to Support Highway Design*. National Highway Cooperative Research Program, Transportation Research Board, National Research Council. National Academy Press. Washington, D.C. 172 pages.

Zeeger, Charles V., R. Stewart, F. Council, and T.R. Neuman. 1994. "Accident Relationships of Roadway Width on Low-Volume Roads." Transportation Research Record 1445. Transportation Research Board, National Research Council. Washington, D.C. pp. 160-168.