Roadway Intersection Inventory and Remote Sensing

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ABSTRACT

The application of remote sensing to the collection of transportation inventories such as roadway features, presents the opportunity to improve upon existing procedures and exploit new technologies. Current procedures for inventory collection do not collect all elements, and such methods are both labor intensive and time consuming. Ongoing research has focused on the development and application of collection methods utilizing remotely sensed imagery. Such techniques would allow the extraction of data which was previously difficult and costly to obtain, while potentially increasing the efficiency and effectiveness of infrastructure feature collection. This paper will discuss efforts to collect inventory elements specific to intersections. Some elements which are not currently collected could possibly be gathered through remote sensing and used for purposes such as safety studies. The expected benefits from remote sensing include a reduced potential for accidents in the field, better equipment utilization and less disruption to traffic.

INTRODUCTION

The Bureau of Transportation Statistics reports that there are over 3,920,000 miles (6,310,000 kilometers) of public roads in the United States (*1*). In order to maintain and upgrade its associated infrastructure, accurate information on features and conditions is necessary (*2*). For this reason "all U.S. state DOT's maintain some type of roadway inventory database of physical features on the roadway" (*3*). Databases can include features such as signs, signals, driveways and bridges; however no single list can capture all of the elements being collected by each state's transportation department (*4*).

Inventory data currently being collected is used by a number of agencies for multiple purposes. State DOT's use inventory data for planning, design, operations, and maintenance (*3*). Infrastructure data is used by the Federal Highway Administration (FHWA) as informational support for its Condition and Performance Reports to Congress, as well as for background data that appears in various agency publications (*5*). Inventory data is also used by governmental agencies, business and industry, educational institutions, the media, and the general public (*5*).

Inventory data is collected mainly to aid in better decision-making. This collected data supports need studies, safety studies, statistical compilations, computer information systems, and feature locations for state DOT's (*6*). However, the methods to collect this data, namely manual and videolog/photolog, require considerable time and resources. Due to the extensive size of roadway networks, data is collected for only a fraction of total mileage. The state of Iowa alone has 39,389 miles of paved roads in its network; this mileage limits the amount of data which can be collected systemwide (pavement conditions, total number of lanes). The remaining data is collected at the corridor level (as necessary) or through statistical samples of roadway segments. The sample data collected for these segments can then be extrapolated to the entire network to provide systemwide inventory estimates.

While it may be adequate for some applications, others are hampered by the limitation of only collecting sample data. One such application that is hampered is safety studies. Federal law requires states to identify and correct hazardous elements along highways (*7*). Typically, this is done for areas where accident frequencies are high, while other potentially dangerous locations remain unexamined. This lack of analysis stems from a deficiency of inventory data associated with those potentially dangerous sites. Current collection methods prevent such data from being collected inexpensively and comprehensively

Current data collection methods are also time consuming and labor intensive. Time is required not only to collect data, but also to reach the collection location. When all time costs are added up, they can equal an inefficient use of both labor and equipment. These inefficiencies ultimately translate into higher financial costs for the agency performing the data collection.

REMOTE SENSING

Remote sensing is defined as "the science of deriving information about an object from measurements made at a distance from the object without making actual contact" (*8*). While remote sensing encompasses numerous detection technologies, three platforms are applicable to transportation: 1) space based (satellite), 2) aerial (airplane), and 3) in-situ (video/magnetic). For the purposes of the research discussed in this paper, only space-based and aerial remote sensing are examined. These forms of remote sensing provide a planar view of roadways, allowing for inventory identification and collection.

RESEARCH OBJECTIVES AND SCOPE OF WORK

The primary objective of this research was to investigate the use of remotely sensed imagery in the collection and measurement of key roadway inventory elements located at intersections. Remotely sensed imagery can be collected with airplanes or satellites without being obtrusive to motorists. Imagery of various resolutions can be gathered by either platform, with higher resolution imagery costing more to obtain than lower resolution imagery. Given that the price of imagery drops with resolution, another research goal was to test images of various resolutions and determine what accuracies were possible or necessary to collect specific elements.

To accomplish the stated research objectives, the following research scope was developed:

1) Identify inventory elements currently being collected by transportation agencies.
2) Identify current data collection methods and their advantages and disadvantages.
3) Conduct a pilot study to determine which inventory elements can be extracted and/or measured from aerial photographs of various resolutions
4) Based on the results of the pilot study, make recommendations concerning the level of resolution necessary to identify each element.Evaluate the advantages and disadvantages of data collection through remote sensing.

INVENTORY DATA

Roadway inventories consist of data "that are collected on each roadways or large sample of roadways that pertain to the roadway itself, not including adjacent buildings and areas, and that they relate principally to describing the identity, function, and physical features of the roadway and right-of-way (ROW)" (*3*). The following sections list common inventory elements which are collected to meet both federal requirements and internal needs.

HPMS

The Highway Performance Monitoring System (HPMS), administered by the FHWA, specifies the minimum amount of data required for collection. HPMS data is collected, assembled, and reported to the FHWA by state highway agencies, local governments, and metropolitan planning organizations (MPO's). Data is collected for all public roads including facilities both on and off state-owned highway systems (*5*). The types of data to be collected have been identified by the FHWA and its partners, stakeholders and customers as those necessary for various needs and applications.

The extensive mileage of roadway systems prevents detailed inventories from being gathered at a reasonable cost. As a result, the HPMS only requires basic information to be collected on a systemwide, or "Universal" basis. Such information includes facility type, number of through lanes and segment length. Remaining data is gathered as a sample from the total roadway mileage available. This data is collected as either "Standard" samples or "Donut" samples. "Standard" samples gather data from a statistically chosen sample of roads on major functional systems. Donut samples gather data for NAAQS non-attainment areas that use the HPMS as the basis of VMT estimates for air quality travel tracking and conformity purposes (*5*).

The HPMS requires a total of 98 data items to be collected. From those 98 elements, 14 were identified as physical inventory items which could be extracted from remotely sensed imagery. These include:

-Section Length
-Number of through lanes
-Surface/Pavement Type
-Lane Width
-Access Control
-Median Type
-Median Width
-Shoulder Type
-Shoulder Width – Right and Left
-Peak Parking
-Number of Right/Left Turn Lanes
-Number of Signalized Intersections
-Number of Stop Intersections
-Number of Other Intersections

Iowa Department of Transportation Data Needs

The Iowa DOT collects additional data for a number of purposes including establishing mileage, updating maps, compiling statistics, establishing computer information systems, locating physical features and for report preparation (*6*). This helps the state determine what present demands on the system are, as well as predict what they will be in the future. The following physical inventory items are collected by the Iowa DOT in addition to HPMS requirements:

-Turning Lane
    Type/Presence
-On-Street parking
    Type
-Traffic Signal
    Structure Type
    Mast type (post, strung, etc.)
-Adjacent land use (commercial, residential, etc.)
-Presence of rumble strips
-Curbing
-Critical intersection thru width
-Railroad crossings
    Number of tracks
    Intersections within 75 feet
        Number of tracks
        Type of crossing protection

As is the case with the HPMS, the Iowa DOT collects samples of information for roadway segments, not individual locations. These surveys collect the quantity of elements on the segment (signs, signals, etc.), but not their location. Therefore, if inventory data for a specific location is desired, it must be collected separately. This translates into additional time and effort requirements to obtain site-specific data.

DATA COLLECTION METHODS

Currently, several methods are used to collect inventory data. These methods vary in technique, equipment utilized, time requirements, as well as other details. Most agencies involved in data collection utilize manual or videolog/photolog methods. A description of each available collection method is provided in the following sections.

Manual Data Collection

Manual methods generally require one or more personnel go out into the field with measuring and recording devices to obtain the desired pieces of information. Measurement devices include distance measuring wheels for length and width data, and global positioning systems (GPS) receivers to obtain positional information. Data is recorded with a pencil and paper or a laptop computer. The limited equipment requirements for manual data collection make the method simple, but not widely applicable to extensive roadway networks. Manual collection is most often used when no other means are available with which to gather the necessary data. This stems from the fact that manual methods require labor, and, subsequently, are dollar intensive.

The following is a list of the advantages and disadvantages of manual data collection:

Advantages

- Minimal training requirements for personnel
- Firsthand visual inspection
- Minimal equipment requirements

Disadvantages

- Data collection personnel exposed to dangerous roadway environment
- Time consuming
- Labor Intensive
- Data collection distracting to motorists

Videolog/Photolog

Photo and videologging provide a visual record of the roadway and its surrounding environment. Both methods utilize a vehicle, often a van, which drives along the roadway while recording devices gather data and produce a visual record which can be examined at a later date. The primary difference between the two methods is their recording mediums, video and pictures. Many videolog/photolog vans also utilize GPS and/or distance measuring instruments, providing further data should it be required.

In terms of labor, photo and video logging are less labor intensive than manual collection methods. Generally, only one or two personnel are required to perform the data collection. Personnel are no longer directly exposed to traffic, as they ride inside the vehicle with the recording instruments. The vehicle serves as protection from the hazards of the roadway environment. Since the collection vehicle often travels at highway speeds, it is also less intrusive to motorists.

The following is a list of the advantages and disadvantages of videolog/photolog data collection:

Advantages

- Faster data collection
- Data collectors removed from direct contact with roadway environment
- Visual record of roadway features

Disadvantages

- Data collection vehicle may be obtrusive to motorists (at low speeds)
- Time consuming as segments must still be driven

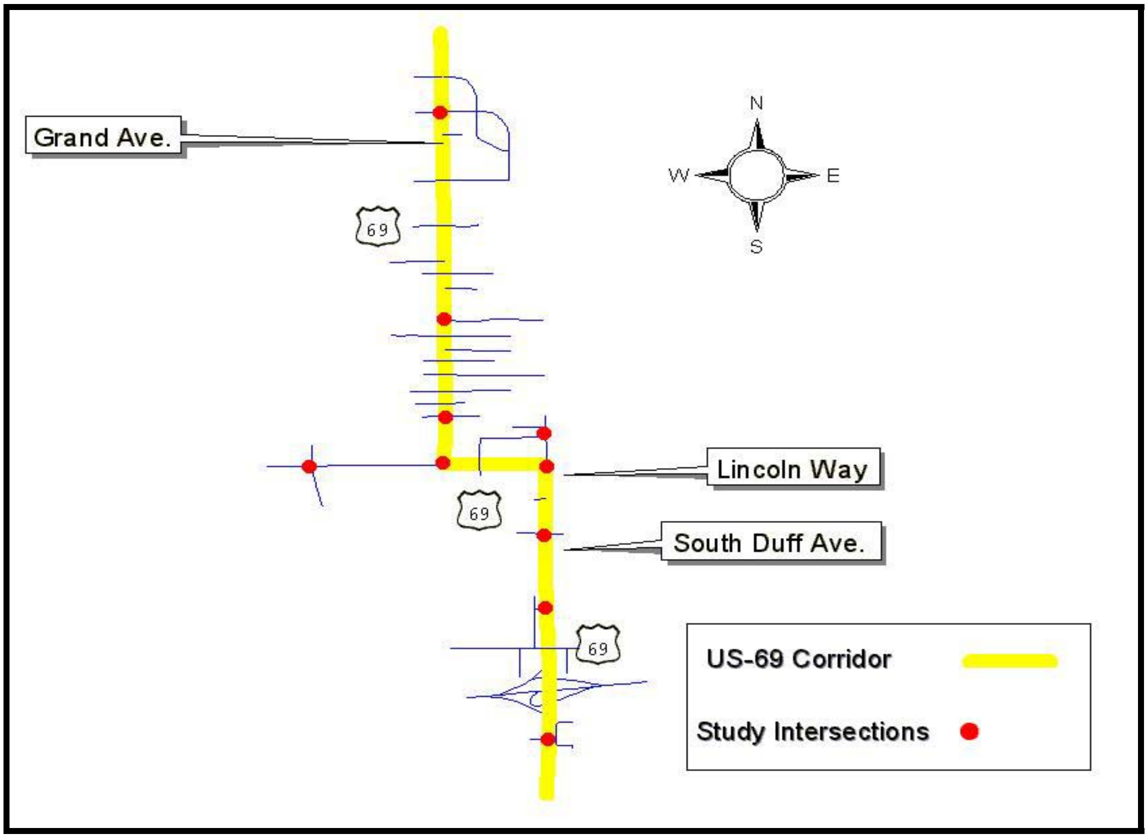
Aerial Photography

While not used to a great extent, aerial images have been employed in data collection. Images taken from an aircraft provide a panoramic view not only of the road network as well as the location of structures and subsequently, land uses. Aerial photos have the advantage of displaying an entire area for analysis. Such a display provides a better picture of how the transportation network interacts with its environment. However, the analysis and interpretation of images requires a great deal of skill. Additionally, good weather is required in order for a flight to take place and produce the required imagery. This limits the available window in which work can be completed. Some elements, such as signs, may not be visible at all. Image processing takes time, and it can also be quite expensive. The storage of the processed images can also become an issue, as the images produced by a number of flights begin take up a large amount of space (either in print or electronic form). As the use of aerial photographs for the collection of roadway inventory features is the subject of this work, a more detailed description of findings, advantages, and disadvantages will be discussed in later sections.

PILOT STUDY AREA

The pilot study for this project followed the US Highway 69 corridor through the city of Ames, Iowa. US 69 is a major north-south arterial. The study corridor also includes three roadway segments, S. Duff Avenue, Lincoln Way and Grand Avenue. The corridor was selected because of the availability of aerial images of various resolutions and because the corridor has a variety of design and inventory elements. The study examined ten intersections, with eight located within the US-69 corridor. An additional two off-corridor intersections were also included in the study. The distance of the corridor segment in this study was 4.1 miles, passing through both commercial and residential areas. Figure 1 displays the study corridor. Images of 2-inch, 6-inch, and 24-inch resolutions were obtained for the study area.

Figure 1: US-69 Pilot Study Area Corridor



Inventory Data Elements Studied

A list of inventory elements to be identified was developed as part of the research. Selection of the data elements was based on those collected by the Iowa DOT and those required by the HPMS. In order to be included in the list, several occurrences of a specific inventory element in the study area was necessary. For example, several medians would have to be present for medians to be included as a data element. The elements selected for inclusion in the study include:

-Through lanes
- Number
- Width

-Presence of crosswalks

-Shoulder
- Presence
- Type
- Width

-Medians
- Presence of median
- Median type
- Width

-Right turn lane
- Presence
- Number
- Width
- Length

-Left turn lane
- Presence
- Number
- Width
- Length

-Location of stop bars

-Presence of pedestrian islands

-Access
- Private access
- Commercial/industrial access

-Signal
- Structure type

-Pavement type

-On-street parking
- Presence
- Type of on-street parking

-Intersection design

-Total roadway width

-Land use

Imagery

This project utilized three datasets of various resolutions:

- 2-inch resolution
- 6-inch resolution
- 24-inch resolution

A fourth dataset of 1-meter resolution was also considered for inclusion; however, it was not due to detection of significant changes (e.g. land use, geometrics), making the dataset outdated.

RESEARCH METHODOLOGY

With the primary elements selected for the pilot study, a trip was made into the field to collection ground truth pertaining to particular elements present at each location. Field data collection included:

- Recording whether a feature was present
- Recording information such as number of lanes
- Measurement of linear features, i.e. lane widths and/or lengths (for turn lanes), using handheld distance measuring wheel

Extraction of Inventory Information from Imagery

ArcView version 3.2 was the GIS tool used to display and manipulate the aerial image datasets. The collection of data was primarily accomplished using manual digitization features present in the software. Map units were set in feet. Elements were identified manually and attributes of the elements populated in an attribute table. Data collection consisted of the following steps:

- Create databases to populate and store extracted information;
- Visually examine imagery to determine presence of feature (i.e. turning lanes);
- Record count data (i.e. number of through lanes) in the appropriate database field;
- Perform linear measurements (lengths, widths) when appropriate, using the ArcView distance measurement tool.

In order to identify each element, a standardized method for identification was developed. The specific method developed for each element is displayed in Table 1.

Table 1: Rules for Element Identification and Measurement

Data Element	Description of collection technique	Element	Description of collection technique
Number of Through Lanes	Identifier: Pavement marking; Position of Vehicle	**Land Use**	Identifiers: Presence of parking; Driveway locations/spacing; Surrounding land use
Through Lane Width	Measured from roadway edgeline to inside lane marking or centerline	**Crosswalks**	Identifiers: Pavement marking
Shoulder Presence/Type	Main Identifier - Color differences between pavement and shoulder material	**Pedestrian Islands**	Identifiers: Sidewalks and vegetation within an intersection
Shoulder Width	Measured from edge of pavement to edge of vegetation	**Stop Bars**	Identifiers: Pavement marking
Parking Presence/Type	Identifier: Vehicle position along roadway; Pavement markings	**Signal Structure/Type**	Identifier: Structure overhanging roadway; Signal heads
Median Presence/Type	Identifier: Color differences from roadway; Object markers	**Right Turn Lane Presence**	Identifiers: Roadway Geometry; Pavement Markings
Median Width	Measurement made from one identified edge of median to the opposite edge	**Right Turn Lane Length**	Measurement made from stop bar to end of solid turn lane marking
Private Access	Total number of private drives within 250 feet (either side) of the intersection; drives identified by surface color and land use	**Right Turn Lane Width**	Measurement made from roadway edgeline to solid turn lane marking
Commercial/ Industrial Access	Total number of commercial and industrial drives within 250 (either side) of the intersection; Drives identified by surface color and apparent land use	**Left Turn Lane Presence**	Identifiers: Roadway Geometry; Pavement Markings
Pavement Type	Identifier: pavement coloration; Type of cracking present if visible	**Left Turn Lane Length**	Measurement made from stop bar to end of solid turn lane marking
Intersection Design	Identifier: Layout of the intersection	**Left Turn Lane Width**	Measurement made from roadway centerline or median to solid turn lane marking
		Total Roadway Width	Measurements made from roadway edge marking to opposite edge marking or curb to opposite curb

PERFORMANCE MEASURES

Performance measures were established to evaluate whether individual features could be extracted from a dataset of a particular resolution and, if so, what the expected accuracy of their linear measurements (lane lengths, etc.) might be. These performance measures include 1) Feature recognition and 2) Accuracy of linear measurement. The following sections provide a more in-depth discussion of each.

Inventory Feature Recognition

Feature recognition is a measure of whether a particular inventory feature can be identified and, if so, whether it can be identified in a consistent manner. For this work, feature recognition was performed by manual photo interpretation. To avoid bias, individuals unfamiliar with the project were asked to examine the images and identify features. This helped to verify that the researcher was not simply identifying elements through familiarity with the study locations. Feature recognition, termed Identification Percentage (IP), was computed as:

$$IP (\%) = (F_g/F_a) * 100$$

Where:

F_a = number of features identified in photos
F_g = number features identified on the ground during field data collection.

Table 2 illustrates the feature identification percentage for each physical element.

Table 2: Feature Identification (FI)

	2 inch			6 inch			24 inch		
Description	Photo	Ground	IP	Photo	Ground	IP	Photo	Ground	IP
Thru Lanes	65	65	**100**	65	65	**100**	34	65	**52**
Shoulders	2	2	**100**	2	2	**100**	0	2	**0**
Medians (Presence)	9	9	**100**	9	9	**100**	5	9	**56**
Median Type	9	9	**100**	7	9	**78**	1	9	**11**
Pavement Type	19	20	**95**	11	20	**55**	0	20	**0**
Intersection Design	10	10	**100**	10	10	**100**	10	10	**100**
Intersection Location	10	10	**100**	10	10	**100**	10	10	**100**
Crosswalks	16	16	**100**	5	16	**31**	0	16	**0**
Pedestrian Islands	3	3	**100**	3	3	**100**	1	3	**33**
Stop Bars	20	20	**100**	16	20	**80**	0	20	**0**
Right Turn Lanes	13	13	**100**	13	13	**100**	7	13	**54**
Left Turn Lanes	20	20	**100**	20	20	**100**	12	20	**60**

Location of driveways was not included in Table 2. Driveways could be identified 100% of the time with all datasets. However, the accuracy in the total number of driveways extracted for each type (Private, Commercial/Industrial) when compared to the ground truth varied between datasets. This was caused, in part, by adjacent land uses sharing driveways. Such driveways could not be easily distinguished with lower resolution imagery, although higher resolutions did allow distinction. Table 3 presents a comparison of actual driveway counts compared to the counts obtained from the datasets

Table 3: Driveway Identification

Dataset	Total Private Driveways from Ground Count	Total Private Driveway from Imagery	Total Commercial Driveways from Ground Count	Total Commercial Driveways from Imagery
2-inch	20	20	19 (1 undercount)	20
6-inch	20	19 (1 undercount)	20	16 (2 undercount; 2 overcount)
24-inch	20	16 (4 undercount)	20	15 (1 overcount); 4 undercounted)

It should be noted that for all identification percentages below 95%, the resolution is not adequate for data collection. For example, the result of 52% of all through lanes being identified by 2-foot imagery is not acceptable. When collecting such data, the *total* number of lanes is required.

Linear Measurements

In order to determine the accuracy of linear measurements extracted from the aerial images, a comparison was made to measurements taken in the field. For example, the 37 measurements of individual through lane widths that could be extracted from 6-inch aerial images were compared to their corresponding field measurement. A t-test was performed to observe any significant difference between extracted measurements and field measurements. The test was performed at a significance level of 0.05 and an estimate of the 95% confidence interval for the expected measurement error was also calculated. The resulting confidence intervals provided an expected error range for linear measurements.

The test statistic was of the form:

$$t = \left[\frac{\bar{d} - \mu d}{s_d / \sqrt{n}} \right]$$

where

$$\bar{d} = \left[\frac{\sum d_i}{d_n} \right]$$ is the mean measurement difference

d_i is the difference between ground and aerial measurements, $(g_i - a_i)$

d_n is the total number of measurements made

$\mu d = 0$, the hypothesized difference

$$Sd = \left[\frac{\sum \left(d_i - \bar{d}\right)^2}{n - 1} \right]$$ is the standard deviation of the measurement differences

$\sqrt{n}$ is the square root of the sample size being examined

National Cooperative Highway Research Program (NCHRP) Report 430, *Improved Safety Information to Support Highway Design*, provided recommended accuracies for linear measurements (*9*). The accuracies presented in this report are recommended for safety studies, which often require a high degree of precision. These benchmarks served as a comparison to the expected error ranges which were generated. The recommended accuracies, as well as the results of each individual element's error range at the various resolutions are presented in Tables 4, 5 and 6.

Table 4: 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 5: 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 6: 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

CONCLUSIONS

The foremost conclusion drawn from this research is that there are significant differences between datasets in the visual identification of inventory features. Higher resolution imagery (2-inch and 6-inch) yielded far more identifiable elements than low resolution imagery (2-foot). Distance measurements relied heavily on the ability to first identify an element. Thus, the use of lower resolution imagery was limited by whether or not a feature could be identified and measured accurately. Automated techniques and better image quality could improve inventory identifications for future work.

The errors generated by lane width measurement ranged from –3.6 to 8.5 feet (95% confidence interval) between the datasets. Even the highest resolution dataset (2-inch) produced an error range of –2.4 to 2.83 feet. With most lane widths falling between 8 and 12 feet, and error of ±3 feet would be considerable. As a result, none of the datasets demonstrated the accuracy required to measure lane or roadway widths, which are useful in applications such as safety studies. The error in length measurements for the datasets ranged from –3.97 to 6.17 feet (95% confidence interval). With the minimum practical length of a turning lane being about 100 feet (about 5 car lengths) an error of 6 feet in measurement is unlikely to affect the results of an application such as a capacity study. The conclusion is that all datasets performed well in measuring lane length.

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. The main advantage to lower resolution data is the ability to collect it quicker and cheaper than higher resolution imagery.

11. ADVANTAGES AND DISADVANTAGES OF REMOTE SENSING

The primary advantage to using remote sensing in inventory collection is the reduction in the amount of time required for collection compared to traditional methods. Significant time savings for data collection were achieved with all resolutions when compared to manual collection. Time comparisons for length and width measurements collected manually versus aerial photo collection are presented in Table 7. It should be noted that the field collection times only include the time actually spent in the field collecting data. Additional time, such as travel to and from sites, as well as between them were not recorded. Such time significantly adds to the total time required to perform manual data collection on vast roadway networks.

An additional advantage of remote sensing in data collection is the opportunity to remove agency personnel from close proximity to dangerous highway environments. The presence of personnel in the roadway environment is not only required of manual data collection, but video/photologging collection as well. While personnel might be protected by a vehicle in video/photologging, their presence on the highway may still be disruptive. With aerial or satellite imagery, a permanent record is created containing all the features in the study area. These features are preserved whether they are used at the time or not. This enables additional data to be collected at a later date without requiring another costly trip into the field. Other advantages include the potential for sharing data, compatibility with GIS software, and change detection through multiple data sets.

A primary disadvantage to remote sensing however, is its cost. A source within the Iowa Department of Transportation estimated that with an in-house capability to ortho-rectify aerial and satellite images, such images can cost $100 per linear mile to acquire. While this cost is not significantly high for limited corridors, the collection of imagery for extensive roadway networks is simply not cost feasible. As such, until data obtains high enough resolution at a low enough cost to cover entire networks, remote sensing for inventory collection may be limited only to spot locations throughout a network.

Table 7: 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

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