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Transportation Infrastructure GIS - Maximized Return on Investment

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ABSTRACT

Enterprise wide GIS require substantial investment from agencies and stakeholders. To maximize the return on the GIS investment of a Transportation Data Model, it is imperative that these systems are populated with complete, accurate, and current data sets. This paper will focus on how to maximize the use of, and leverage a GIS for Transportation Infrastructure and Transportation Asset Management in Halton Region and present an approach to data collection focusing on accuracies, asset (features), and attribute requirements. In addition, methods of gathering the data will be contrasted such as handheld data collection practices and mobile digital video surveys and an analysis will be discussed from a cost/benefit view. More importantly, the benefits of digital mobile video survey data collection will be addressed illustrating the many value added components utilizing SDE with ArcIMS and ArcGIS Suite.

INTRODUCTION

The Regional Municipality of Halton is located on the western end of Lake Ontario and serves a population of 430,000. The organization has been using GIS technology since the early 1990's. In 2001, the Region commenced the implementation of an enterprise wide GIS utilizing ArcSDE. Upon implementation of the SDE environment, it was imperative to take advantage of the tools available from a geodatabase to model Transportation Infrastructure along the Regional road network.

This paper focuses on how the Transportation Services Section within The Regional Municipality of Halton maximized the use of GIS technology for Transportation Infrastructure and Transportation Asset Management along the 312 kilometres of Regional road network within its urban and rural areas. Emphasis will be placed on the approaches, technology, and method of data collection that was used to initially populate the geodatabase. In addition, value added components and bi-products that can be realized through utilizing an enterprise wide GIS solution for Transportation Infrastructure will also be discussed.

TRANSPORTATION DATA MODEL

As Halton Region began to embark on an enterprise GIS solution for transportation infrastructure, Transportation Services sought to capitalize on the technology available. The primary obstacle was the number of transportation related data sets being managed in non-traditional GIS solutions. It was realized that the method of maintaining this data was intense, research was conducted to find the best solution available for the capturing and maintenance of transportation related assets. Amalgamating the various data sets from the various data sources into one geodatabase, as well as building an the existing ESRI data model, were both identified as the main goals.

To ensure that the transition of data maintenance and data collection was achievable within the geodatabase it was imperative to meet with all divisions and sections within the Planning & Public Works department. All existing data sources and the information available from paper maps, mylar's and CAD drawings were catalogued. It was established that most of the information was dated and compiled from many road related projects over time. Although there was not one complete set of data, it was noted that these data sources would become valuable in the future for updates as changes occurred along the road Right-Of-Way (ROW) for Asset Management. A review of what data already existed and which data sets were valuable was the objective. The link between many of the datasets became more evident as each division/section was approached.

In 2002, a transportation data model was developed with the collaboration of internal resources and an external consultant. The external consultant developed and integrated the new Transportation Data Model (termed TRN) within the Regions Enterprise GIS. As part of the consultant's work, a gap analysis workshop was held to review current and future datasets, attributes required and to ensure that the rules and relationships between features were established to maximize the use of the linear referencing system within the TRN for modeling assets. The result was the development and implementation of a geodatabase to maintain Transportation Infrastructure for Transportation Asset Management. Upon implementation it was essential to integrate existing datasets and establish a prioritization list of the data that needed to be populated to fill in the gaps identified (Table 1). A phased approach was adopted, given that most of the data needed to be collected and integrated from various data collection methods.

Table 1 – Assets and Data Collection Phasing

Phase	Asset	Phase	Asset
1	Guide Rail	2	Access
1	Intersection	2	Boulevard
1	Marking Line	2	Bridge
1	Marking Point	2	BusStop
1	Marking Poly	2	Curb / Gutter
1	Master Controller	2	Hand Hole
1	Median	2	Inlaid Delineater
1	Number Of Lanes	2	Landscape Area
1	Pole	2	Loop Detector
1	Sign Location	2	No Parking
1	Sign Placement	2	No Passing
1	Sign Type	2	No Stopping
1	Street Centreline	2	No Trucks
1	Street Light	2	No Turns
1	Traffic Controller	2	Pavement
1	Traffic Signal	2	Railway Crossing
		2	Recreational Path
		2	Road Speed
		2	Sidewalk
		2	Wall

DATA COLLECTION SELECTION METHOD

One of the most important aspects of maximizing the return on investment of the TRN was to ensure that the geodatabase was populated with complete, accurate and current data utilizing a data collection method that could gather all the required data in a cost effective manner. The TRN was implemented for Transportation Infrastructure and Transportation Asset Management, which would require positional data to be accurate to sub metre for use within the existing GIS and other daily work activities within Planning and Public Works.

In order to facilitate the data requirements of the TRN, research was conducted on the data collection methods of each asset and the level of effort required. Each asset was contrasted and compared documenting the advantages and disadvantages in regards to positional accuracy and validity of attribute data collection using various data collection technologies; Digitization, Handheld GPS and Mobile Digital Video Survey as outlined in (Table 2).

<u>Table 2 – Data Collection Methods – Advantages and Disadvantages</u>

Type	**Method**	**Data Sources**	**Advantages**	**Disadvantages**
Digitization	Tracing/Digitizing Tablet	CADS Drawings/Mylar's/Paper Maps	Labour costs	Data currency
	On-screen	Orthophotography	Timeframe	Positional accuracy
Hand Held GPS	Field Data Collection	GPS Unit/Field Staff	Accuracy control	Resource intensive
	In office data compilation			Weather/satellites
				Attribute collection
Mobile Digital Video Imagery	Mobile Collection	Digital Video Imagery / GPS Data	Positional accuracy	Weather
	In office data extraction		Attribute accuracy	Cost of technology if purchased
	and compilation		Immediate Inventory	
			No field revisits	

In order to review the advantages and disadvantages of the data collection methods as referenced in Table 2 a scoring matrix was devised as outlined in (Table 3). To finalize the decision of what data collection method was best based on geometry and attribute data collection, each asset was scored (Table 4).

Table 3 – Data Collection Methods Scoring Codes – Geometry/Attribute

Code	**Geometry**
1	Data collection method not achievable
2	Data collection method intensive
3	Data collection method accomplishable
4	Good data collection method for task
5	Ultimate data collection method for task

Code	**Attribute**
1	Attribute data collection method not achievable
2	Attribute data collection method intensive
3	Attribute data collection method accomplishable
4	Attribute good attribute data collection method for task
5	Ultimate attribute data collection method for task

Table 4 – Data Collection Methods Scoring Matrix

			Digitize	**Digitize**	**Handheld GPS**	**Handheld GPS**	**Mobile Digital Video Survery**	**Mobile Digital Video Survery**
Phase	**Asset**	**Feature Type**	**Geometry**	**Attribute**	**Geometry**	**Attribute**	**Geometry**	**Attribute**
1	Guide Rail	Geometry/Attribute	3	3	4	4	5	5
1	Intersection	Geometry/Attribute	4	3	4	4	5	5
1	Marking Line	Geometry/Attribute	3	3	2	4	5	5
1	Marking Point	Geometry/Attribute	4	4	4	4	5	5
1	Marking Poly	Geometry/Attribute	4	4	3	4	5	5
1	Master Controller	Geometry/Attribute	4	4	4	4	5	5
1	Median	Geometry/Attribute	3	3	3	4	5	5
1	Number Of Lanes	Geometry/Attribute	4	4	3	4	5	5
1	Pole	Geometry/Attribute	2	2	4	4	5	4
1	Sign Location	Geometry/Attribute	2	2	4	4	5	5
1	Sign Placement	Attribute	2	2	4	3	5	5
1	Sign Type	Attribute	2	2	4	3	5	5
1	Street Centreline	Geometry/Attribute	4	4	4	3	5	4
1	Street Light	Geometry/Attribute	2	2	4	4	5	5
1	Traffic Controller	Geometry/Attribute	4	4	4	4	5	5
1	Traffic Signal	Geometry/Attribute	2	2	4	4	5	5
2	Access	Geometry/Attribute	3	3	4	4	5	5
2	Boulevard	Geometry/Attribute	3	3	3	4	5	5
2	Bridge	Geometry/Attribute	4	5	4	4	4	5
2	BusStop	Geometry/Attribute	4	4	4	4	5	5
2	Curb / Gutter	Geometry/Attribute	2	3	4	4	5	4
2	Hand Hole	Geometry/Attribute	4	4	5	4	3	3

2	Inlaid Delineater	Geometry/Attribute	4	4	3	4	5	5
2	Landscape Area	Geometry/Attribute	3	3	3	4	5	5
2	Loop Detector	Geometry/Attribute	3	3	4	4	2	1
2	No Parking	Attribute	2	2	4	3	5	5
2	No Passing	Attribute	2	2	4	3	5	5
2	No Stopping	Attribute	2	2	4	3	5	5
2	No Trucks	Attribute	2	2	4	3	5	5
2	No Turns	Attribute	2	2	4	3	5	5
2	Pavement	Geometry/Attribute	2	2	4	3	5	5
2	Railway Crossing	Geometry/Attribute	4	3	4	3	5	5
2	Recreational Path	Geometry/Attribute	4	4	4	4	5	5
2	Road Speed	Attribute	3	3	4	4	5	5
2	Sidewalk	Geometry/Attribute	4	4	4	4	5	5
2	Wall	Geometry/Attribute	3	3	4	4	5	5

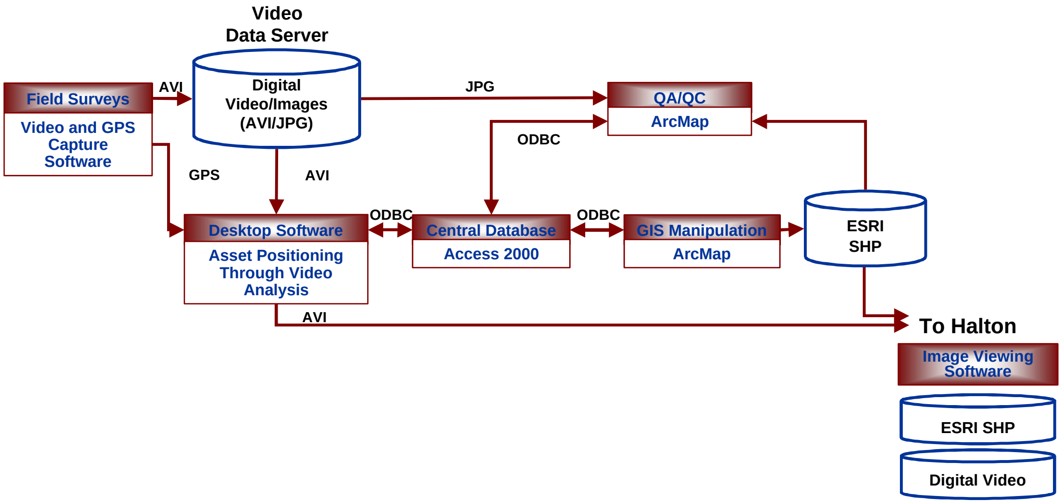
The end result of the review indicated that Mobile Digital Video Survey satisfied the needs of data collection from positional accuracy and attribute data collection for many of the assets.

MOBILE DIGITAL VIDEO SURVEY

Once the data collection method was selected, an analysis of the best method to extract the data was determined. Outsourcing the extraction and compilation was more cost effective than acquiring software and adding resources to meet the project schedule. More specifically, the data collection requirements were to gather digital video coupled with a GPS system to capture Transportation infrastructure along the Regional Road ROW at sub metre accuracy.

After consultation the overall process implemented to meet the project requirements for data capture and asset inventory was established (Figure 1).

Figure1

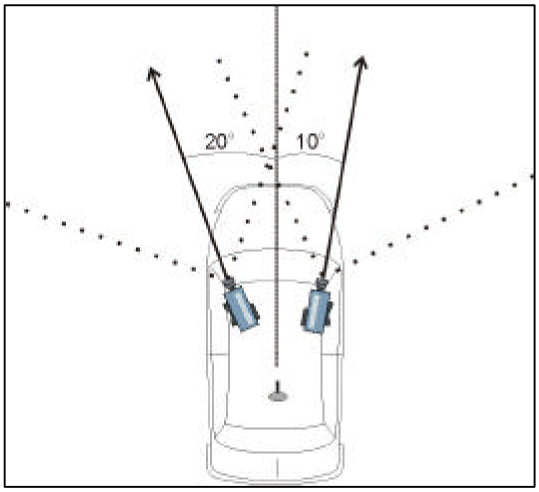


Field Surveys

The first step in the process was to gather the raw digital video and GPS data.

Digital Video

Figure 2



With the use of 2 high-definition digital video cameras (1280 x 960 pixels and 1600 x 1200 pixels) mounted inside the data collection vehicle, digital image streams were provided that gave a full panoramic view of the ROW Figure 2). Static calibrations were performed both prior to and following the field data collection to ensure that the orientation of the cameras did not change throughout the survey. This was an essential quality control process to ensure that the accuracies of the future asset extraction met sub metre data requirements.

The images were collected in both directions of travel from the left and right cameras through the survey routes. The images were stored on external hard drives in digital format, which allowed for quick and easy, non-linear access to the images and corresponding geo-referenced data. The digital imaging system was configured to collect digital images at 3-meter intervals, which were stored within AVI files. Each image gathered by the acquisition system was assigned a GPS coordinate in real time utilizing the system described below.

Inertial GPS Data and Differential Correction Methods

Mobile Digital Video Survey data collection is best applied to collecting transportation infrastructure due to the nature of the features location relative to the roadway and the positional accuracy obtained through the inertial aided GPS navigation system. The system that was operated in the project is an extremely advanced device to the extent that it is required to be licensed by the US Department of State in order to use the system in commercial applications. The advantage of such a system clearly out-weighs the conventional GPS tools in the marketplace. Essentially, the Inertial GPS system ensures that there is, at all times, a 100% stream of GPS being collected, regardless of the vehicle’s relative “view” of the sky and number of satellites in lock. The equipment proved to be invaluable since tree canopies and urban canyon (buildings) would have hindered conventional GPS data collection. The loss of GPS signal is significant in these environments and the result is incomplete vehicle GPS traces and would have meant that positioning of features from the digital video would not be possible. The use of the Inertial GPS provided 20 coordinate readings every second, regardless of the tree canopy or urban canyon in the heavily urbanized areas. This frequency was essential with respect to the future extraction and locating of all assets within the required road network from the digital video.

The system consists of two GPS receivers that are calibrated and mounted in specific locations on the roof of the survey vehicle, as well as an Inertial Measurement Unit (IMU) and a precise Distance Measuring Instrument (DMI). The IMU is comprised of three accelerometers and three gyroscopes. The data from the two GPS receivers and the IMU is passed through a Kalman Filter, which stores the algorithms to determine the optimum blended GPS solution for each individual coordinate reading. For example, if the system determines that the GPS signal is below an acceptable threshold then the system will utilize the IMU data and will fill in the headings to create a continuous GPS trace. In this regard, the total loss of GPS signals, or even small degradation in signals, will not impede the collection of continuous GPS traces.

The GPS system also provided a key quality control tool for the field technicians operating the vehicle. Through a mapping interface displayed on a computer in the vehicle, the system was loaded with the Region's Street Centerline and provided a precise real-time location of the vehicle as it traveled through the survey routes.

The system also integrates a real-time differential correction method to improve accuracies of the GPS data. For the real-time use of the system in the field, the Canadian DGPS (C-DGPS) correction source network was utilized. To further improve the accuracies of the GPS system, the GPS data was also post processed through proprietary correction software, developed by the manufacture of the Inertial GPS system, utilizing base station data collected at a control point in the center of the Region.

ASSET EXTRACTION

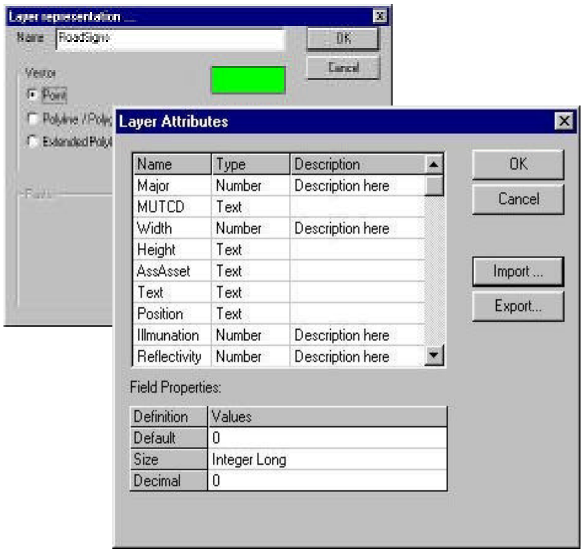
Once the raw digital video images and GPS data were collected in the field, the data was processed utilizing video analysis software for feature extraction into the structure of the TRN. In general, the Transportation Infrastructure assets, as defined in the TRN model, were identified from the video images and extracted into a database with geo-referenced coordinates. In addition, each asset was observed and assigned attribute data such as asset type, material types, and codes. Each of the required TRN assets to be collected for the mobile data collection were imported into the software for feature extraction of:

-3D Points – {e.g. supports, signs, signals, lights, pavement markings}
-3D Extended Polylines – linear feature that extend across multiple images
    –{e.g. pavement markings, guiderails}
-3D Polygons – linear feature that extend across multiple images
    –{e.g. medians, pavement marking areas}

Each of the asset's attribute information was configured through customized entry forms within the software and relationships between features were defined. For the TRN model, a Pole was related to many Sign Locations, Street Lights, and Traffic signals. The video analysis software ensured that all features were linked, where appropriate, to each respective infrastructure item.

A typical attribute set-up that may be selected for a street sign is illustrated in Figure 3.

Figure 3



Name: RoadSigns

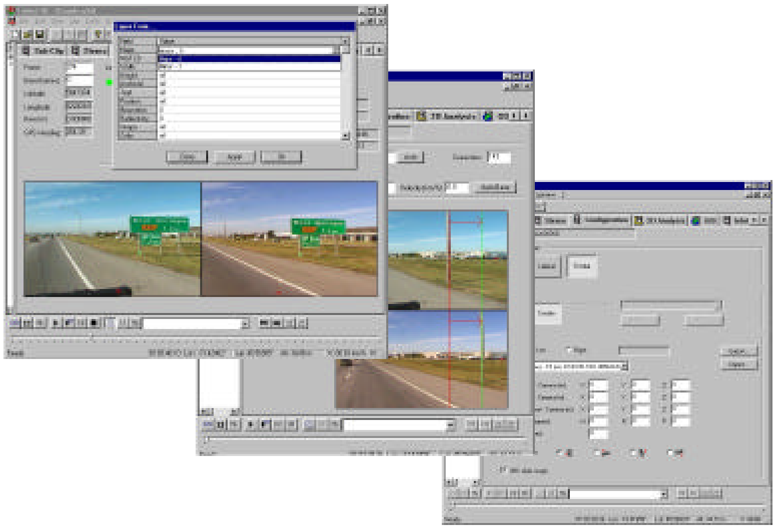
Name	Type	Description
Major	Number	Description here
MUTCD	Text	
Width	Number	Description here
Height	Text	
AssAsset	Text	
Text	Text	
Position	Text	
Illmunation	Number	Description here
Reflectivity	Number	Description here

Field Properties:

Definition	Values
Default	0
Size	Integer Long
Decimal	0

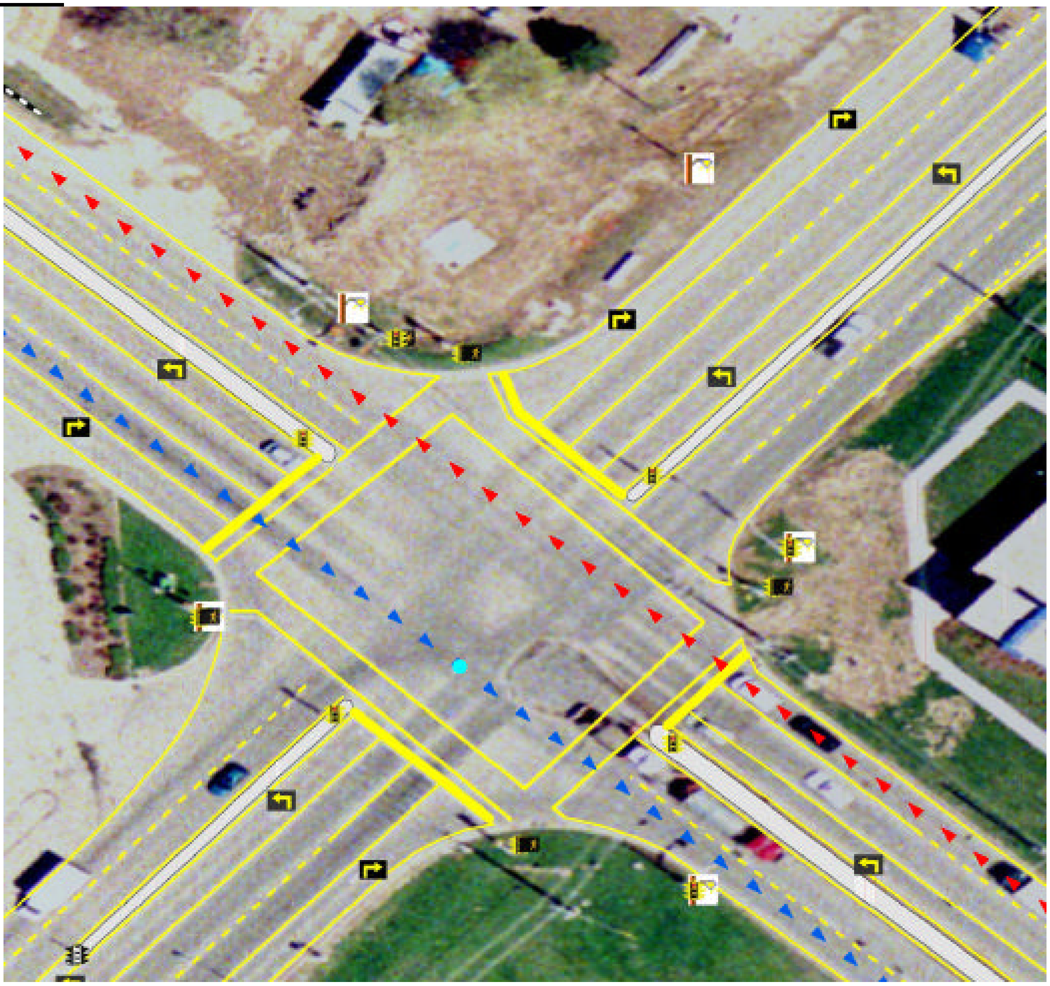
Once the software was configured to meet the project requirements, the video data was observed and the assets were extracted to a shapefile when encountered on the video. By utilizing known calibration data of all on-board systems (camera orientation relative to the GPS unit), X, Y, and Z coordinates for the respective assets were generated within each image frame. This was accomplished by clicking on two sequential images at the same anchor point (i.e. base of a support) and through stereoscopic technology an accurate coordinate was derived (Figure 4).

Figure 4



In conjunction with the extraction process, ArcGIS was used as a quality control mechanism. The shapefile that was populated through the video extraction software was also connected to ArcGIS through an ODBC link. In addition, through the ODBC link, the video survey was viewed with other data sources such as orthophotography to do a quality control/quality assurance to spot-check positional accuracy and attribute completeness on the database (Figure 5).

Figure 5



Once all asset features were extracted from the software and QA/QC checks were done, the data was converted into shapefiles. The data was uploaded into ArcSDE via ArcToolBox. Upon completion of the asset extraction process many value added components from the mobile digital video survey was available within the TRN.

BENEFITS REALIZED

The Transportation Infrastructure collected as part of the project has been applied to the daily maintenance and operations of the Regional road network. As part of the asset management program, the data has been applied to Capital Budgeting for Pavement Markings, Pavement Management and managing the inventory of Poles, Signs, Traffic Signals, Medians, Guide Rails and Street Lights.

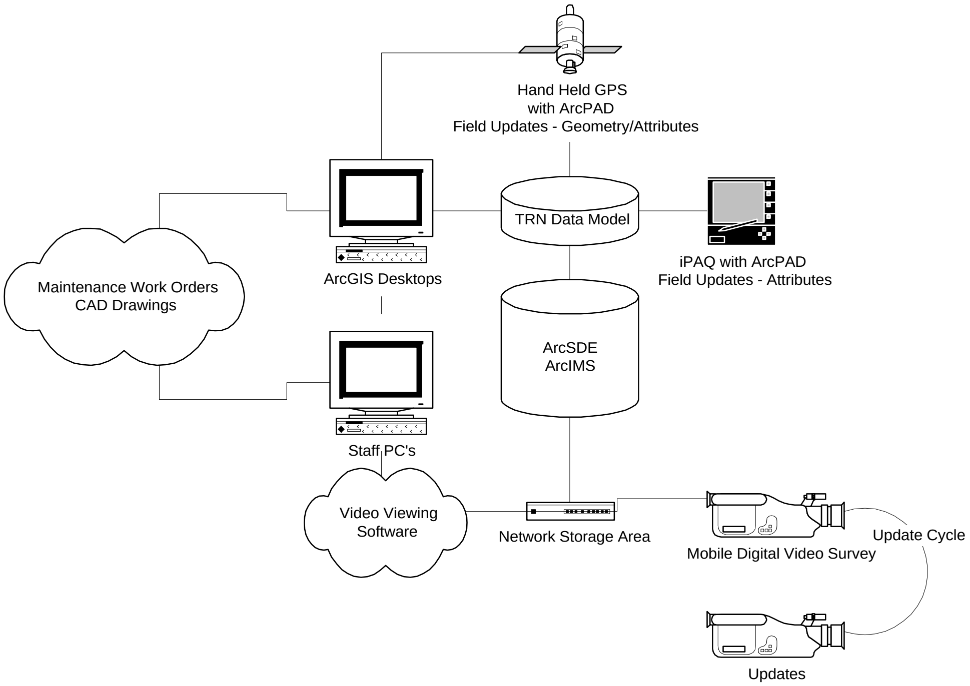
Mobile Digital Video Survey not only provided a data collection method that met the positional accuracy and attribute data collection needs, additional value added components were realized upon completion of the project that make digital video coupled with GPS data a valuable asset to any organization that maintains and operates a road system.

The digital video imagery (AVI) files coupled with the GPS data provided the following benefits that would not have materialized from digitization and/or handheld GPS data collection;

- Digital video archive of the road network
- Visuals for public presentations
- Customer complaint review feedback tool
- Reduced field visits
- Dataset to review Engineering applications
- Dataset for emergencies
- Dataset to catalogue and remove illegal signs
- Dataset for non-transportation assets within the ROW (Hydro Line Crossings and Fire Hydrants)
- Integrate AVI data with ESRI software
- Populate transportation data using Linear Referencing (Events)

Figure 6 illustrates how the Mobile Digital Video Imagery tied with GPS data is utilized with the Enterprise wide GIS.

Figure 6



In conclusion, Mobile Digital Video Survey joined with GPS data was clearly the best approach to data collection for Transportation Infrastructure and Transportation Asset Management along the ROW. By utilizing this data collection technology, the Region was able to maximize the return on the investment of the TRN and populate the data with complete, accurate and current data in addition to the benefits of integrating the digital video data with the Enterprise wide GIS. To ensure that this dataset is kept complete, accurate and current, ArcPad software and mobile GPS technology have been chosen to maintain the current and future features in the TRN with the ArcGIS suite of software for the years to come.

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