Integrating Various Terrestrial and Aerial Sensor Data for Transportation Projects

JIM PETERSON, Wildwood Missouri
KEN SPRATLIN, Westminster Colorado

ABSTRACT

Various terrestrial and aerial sensors are being used to facilitate data collection for transportation projects. Many sensors are common among the different collection methods. Users at different phases of the roadway life cycle may have user specific requirements for the data collection. Users have needs ranging from low to high accuracy, sparse to fine detail, Geographic Information Systems (GIS) to Computer Aided Drafting (CAD) formats, and many variations of each. End users and/or customers need models that contain data collected from many sources and by many industry disciplines. The source of the data collection is secondary to the use of the model and in some cases may be transparent. The different types of data need to merge because there are so many sources of data throughout the roadway life cycle and there is a need for a common three-dimensional (3D) model.

There are barriers that need to be addressed to facilitate a convergence of data into one common model. Common control must be available throughout the roadway life cycle. The strengths and weaknesses of each type of data collection should be evaluated for practical application to collect the attributes needed to accompany a 3D model. Software tools need to be created that can analyze and merge data from multiple sources.

The different data collections have been considered in the past to be "stand alone" without consideration being given to other user's needs along the roadway life cycle. This view limits the synergy that can be gained by foresight, and increases life cycle data collection cost. The deliverables are not just for survey, mapping, or GIS. The deliverable should be considered as a piece of the model that can be carried throughout the roadway life cycle. The different collection methods complement each other to make a complete model. This paper identifies the needs for the integration of aerial and terrestrial sensor data for transportation projects and the barriers that are hindering this integration.

1. INTRODUCTION

Various terrestrial and aerial sensors are being used to facilitate data collection for transportation projects. Many sensors are common among the different collection methods. Users at a specific phase of the roadway life cycle may have different requirements for the data collection. The roadway life cycle is shown below in Figure 1.1:

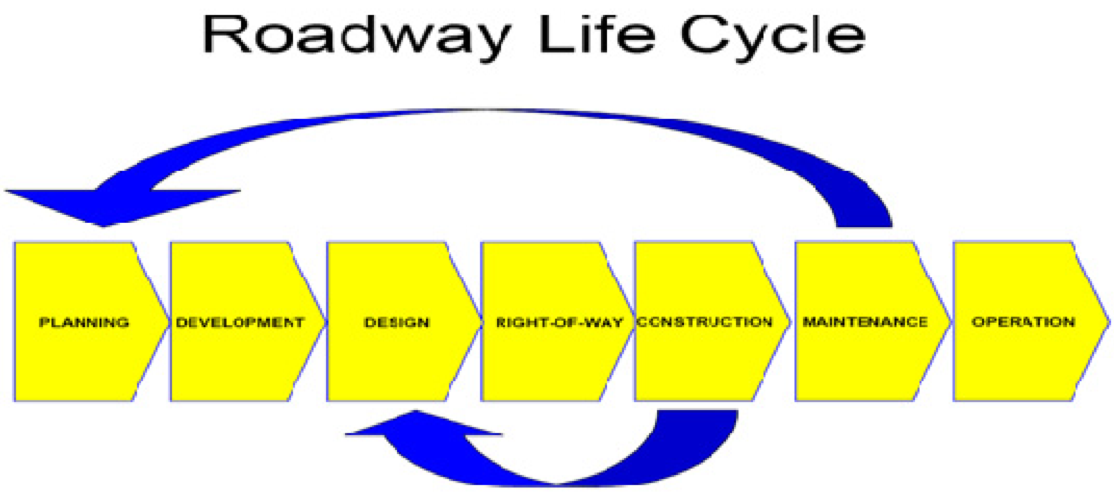

Fig. 1.1: Roadway Life Cycle.

Users have needs ranging from low to high accuracy, sparse to fine detail, GIS to CAD formats, and many variations of each. End users and/or customers need models that contain data collected from many sources and by many industry disciplines. The source of the data collection is secondary to the use of the model and in some cases may be transparent. The different types of data need to merge because there are so many sources of data throughout the roadway life cycle and there is a need for a common three-dimensional (3D) model.

There are barriers that need to be addressed to facilitate a convergence of data into one common model. Common control needs to be available throughout the roadway life cycle. The strengths and weaknesses of each type of data collection should be evaluated for practical application and to be able to collect the attributes needed to accompany a three dimensional (3D) model. Software tools need to be created that can analyze and merge data from multiple sources.

Methods commonly used for air collection in the past are now becoming more common for terrestrial collection. The progression towards the use of mobile mapping is bringing the two collection methods closer together. Aerial and terrestrial data collections both generate very similar deliverables and/or complement each other for a complete deliverable package. They can both contribute to the same 3D model. Their differences such as collection speed, point density, nadir or oblique views, and collection costs can be used to complement each other. This paper identifies the needs for the integration of aerial and terrestrial sensor data for transportation projects and the barriers that are hindering this integration.

2. CONTROL

Data from individual projects are treated as if they have little value to other users in the roadway life cycle. Consideration has not been given for data integration. Convergence of data into a single 3D model is not being implemented. Permanent and semi-permanent common control should be available throughout the roadway life cycle. Time and money are being wasted providing control over and over again at different stages. The use of assumed project coordinates prevents the ability to use known datums without a site calibration. Control provided on a consistent horizontal and vertical datum will streamline the data integration.

2.1. Permanent and Semi-Permanent Control

Providing and maintaining permanent and semi-permanent control throughout the roadway life cycle will save money. Control should not be thought of only of the conventional type. Control monuments in the ground are essential, but we should not stop there. All control needs throughout the roadway life cycle should be accommodated. Control should address the needs of traditional survey, tripod mounted scanning, mobile mapping, and aerial imagery and Light Detection and Ranging (LiDAR). Installed concrete monuments may only be needed every 20-30 miles or 30-50 kilometers. Intermediate control could be surveyed in with Global Navigation Satellite Systems (GNSS) for traditional survey and tripod mounted laser scanning projects as needed. Semi-permanent intermediate control could be established for mobile mapping and aerial collections. Spherical targets could be mounted as full or half spheres at 1 mile or 2 kilometer intervals. Full spheres as shown in Figure 2.1 could be stand alone mounted on a permanent base. Half spheres could be mounted on bridges and other structures with vertical flat surfaces that are visible from the roadway. Spheres and object control points can be

Fig. 2.1: Spherical Target.

used to further rectify data and give the user control over horizontal accuracy. Semi-permanent aerial targets could be installed that could be used for aerial imagery and LiDAR.

Construction projects could install the control when the transportation project is being built. Transportation officials and/or consultants could install the control as needed. Consistent control would therefore be available throughout the roadway life cycle. This will save time and money by reducing the repetitive establishment of survey control for every individual project. This additionally facilitates the use of common datums, which are discussed in the next section.

2.2. Common Datum

Control planning with foresight should involve utilizing a single horizontal and vertical datum created for long distances over the earth's curved surface. Some examples are the use of state plane coordinates and similar regional coordinate systems and large scale vertical datums such as NGVD 88 with the use of a current geoid model. Thought should be given to using earth-centered coordinate systems. End users would have data on the same system throughout the roadway life cycle by forcing the use of a common datum on all projects. This is the first step in convergence of data into one common 3D model.

Readily available control data in a common datum would integrate data immediately and streamline the convergence towards a common 3D model among users. A database could be maintained and available on-line. A similar database is being implemented by the USGS and called Online Positioning User Service Data Base (OPUS-DB). Surveyors could then focus more on maintaining and upgrading the control system than performing topographic surveys in hazardous traffic conditions as mobile mapping and airborne LiDAR become more commonplace. The establishment of permanent and semi-permanent control on a common datum is the first step to aerial and terrestrial data integration.

3. DATA COLLECTION APPLICATION

The strengths and weaknesses of each type of aerial and terrestrial data collection should be evaluated for practical application to collect the attributes needed to accompany a 3D model. Aerial and terrestrial collection methods have been seen as competing with each other and/or being distinctly different and independent solutions. The aerial collection methods are typically nadir-oriented imagery and LiDAR. The terrestrial collection methods are traditional surveying, Geographic Information Systems (GIS) asset mapping, tripod mounted laser scanning, and mobile mapping.

Aerial mapping can obtain large areas at a relatively low cost and have traditionally replaced topographic ground surveys in the planning stage of a roadway life cycle. The detail and accuracy of a topographic ground survey have traditionally replaced aerial mapping during the development and design stages of the roadway life cycle. Laser scanning and mobile mapping are viewed as competitors with traditional surveying. Asset collection is also viewed as replacing traditional surveying. The differences that divide the use of these collection methods do not make them competitors. The different collection methods complement each other to make a complete 3D model.

3.1. Aerial

Aerial collection speeds are approximately 65-120 knots. The slower the collection speed, the greater the density of points for a given LiDAR sensor. Image collection is less sensitive to speed, and pixel resolutions can be as small as 3 inches. LiDAR point densities are commonly found to be 1-10 points per square meter and increasing. Helicopters collect the greater density of points. Coverage is a function of the altitude of the flight but is typically a narrow corridor of approximately ½ mile or 1 kilometer. This usually allows for collection from right of way to right of way including adjacent drainage areas.

LiDAR points are not individually intelligent. The point possesses intelligent data that must be compared to its' neighboring points for surface or object recognition. This less intelligent individual data is acceptable for drainage studies and for unobstructed surfaces. It is also the better solution for obtaining surface data in areas with tree canopy. Direct georeferenced LiDAR accuracies range from 30-50cm with the use of tightly coupled GNSS/IMU post processing. Point clouds adjusted to ground control have accuracies that range from 5-10cm.

Aerial data is traditionally delivered in a computer aided drafting (CAD) format compatible with Microstation or AutoCAD.

3.2. Terrestrial

The terrestrial data collection methods are traditional surveying, GIS asset mapping, tripod mounted laser scanning, and mobile mapping. Mobile mapping can be further broken down into roadway asset collection, pavement inspection, and surveying.

3.2.1. Traditional Surveying

Traditional surveying methods can collect approximately ½ mile per day of right of way to right of way topographic survey per survey crew. The point specific detail is unmatched. Every point taken is intelligent. Field to finish line coding is input in the field for fast line creation and contouring in the office. Survey field codes for a typical roadway cross section are shown in Figure 3.1.

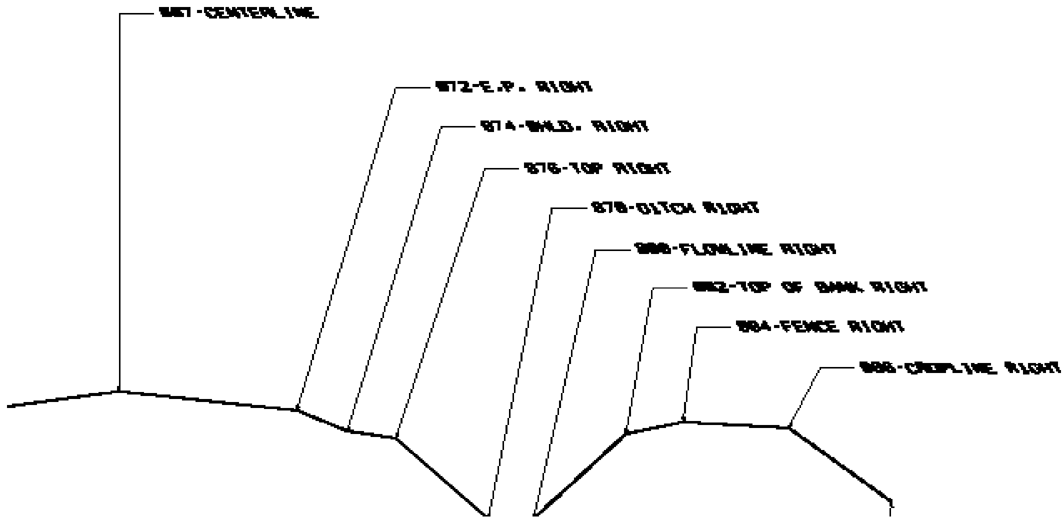

Fig. 3.1: Survey Field Coding Image Courtesy of Illinois Department of Transportation.

However, surveyors are put in harm's way, and traffic is impeded. It has the slowest rate of collection when compared to the other collection methods. Survey data is traditionally delivered in a computer aided drafting (CAD) format such as Microstation or AutoCAD.

3.2.2. GIS Asset Mapping

Asset mapping has traditionally been performed by physically walking to every asset. Each asset has a location along with the appropriate metadata. The list of data elements is extensive. Table 3.1 below is a list of asset categories and the associated features as determined by the Federal Highway Administration.

Table 3.1: Roadway Features.

ROADWAY FEATURES				
ASSETS	GEOMETRIC FEATURES	INTERSECTION	PAVEMENT CONDITION	ROADWAY INVENTORY
• Barrier Systems	• Grade	• Configuration and Dimensions	• Pavement Edge	• Bridges • Approaches
• On-Street Parking	• Cross Slope	• Traffic Control	• Pavement Profile	• Driveways
• Pavement Markings	• Curvature	• Signalized Intersections	• Skid Characteristics	• Lanes
• Roadside Obstacles		• Stop Controlled Intersections	• International Roughness Index	• Median
• Rumble Strips				• Rail Crossings
• Sidewalk				• Ramps
• Signs				• Shoulder
• Street Lighting				

Examples of metadata or attributes for a transportation project are location, size, color, length, condition, etc.

Collection rates vary based on the number of assets to be collected. The collection rate is generally thought to be slightly faster than survey collection rates of ½ mile per day because of the manual collection methods. The location of the asset at a high accuracy is not usually required. Asset data is traditionally delivered in a GIS and/or database format such as a shapefile or geodatabase.

3.2.3. Tripod Mounted Laser Scanning

Tripod mounted laser scanning can collect as much as 1-2 miles per day of right-of-way to right-of-way scanning. Georeferenced oblique imagery is also collected simultaneously. The point cloud is a random cloud of points. The density is usually enough to allow for specific points to be extracted and/or created. The use of the georeferenced imagery as shown in Figure 3.3 assists in this task. Rich data is collected and 3D models are easily created from the point clouds. Exposure to traffic is reduced over traditional surveying. Access to the lanes of traffic is reduced and may not be necessary. A virtual site is viewable by the end user. Tripod mounted laser scanning data for transportation projects are delivered in a CAD format compatible with Microstation or AutoCAD.

3.2.4. Mobile Mapping

Mobile mapping is predominately being used for roadway asset collection and pavement inspection. Recently, it has been used for its' LiDAR and image collection to produce survey data.

Fig. 3.2: Trimble Cougar Mobile Mapping System Image Courtesy of Trimble Navigation Ltd.

Mobile mapping collection speeds are approximately 30-55 mph. The slower the collection speed, the greater the density of points for a given LiDAR sensor. Image and roadway asset collection is less sensitive to speed and results in a greater collection rate than the survey data. Pavement maintenance has typically required slower speeds, but has recently achieved faster collection speeds. Automated tools that recognize some categories of assets have begun to emerge, and promise to greatly reduce office production time.

3.2.4.1. Mobile Survey

Point densities for a mobile survey collection are commonly found to range from 10-1000 points per square meter. Coverage is a function of the sensors and is limited by line of sight. Typically the pavement and adjacent shoulder can be collected without problem. Occasionally, the side slopes, ditches, and right of way can be obtained. Direct georeferenced LiDAR accuracies range from 5-10 cm with the use of tightly coupled GNSS/IMU post processing. Point clouds adjusted to ground control have accuracies that range from 1-5 cm.

Objects and topographic items can be semi-automatically generated. Transportation survey field coding for creating break lines and topographic features can be extracted from terrestrial LiDAR data.

Many software packages for processing terrestrial point clouds have a feature coding or virtual surveying function to expedite the survey field coding. Survey field coding shown in Figure 3.1 can be used to filter the terrestrial LiDAR into a more traditional transportation deliverable. The coding can be performed in a view where edges can be observed if images can be oriented to the point cloud such as the view shown in Figure 3.3 below.

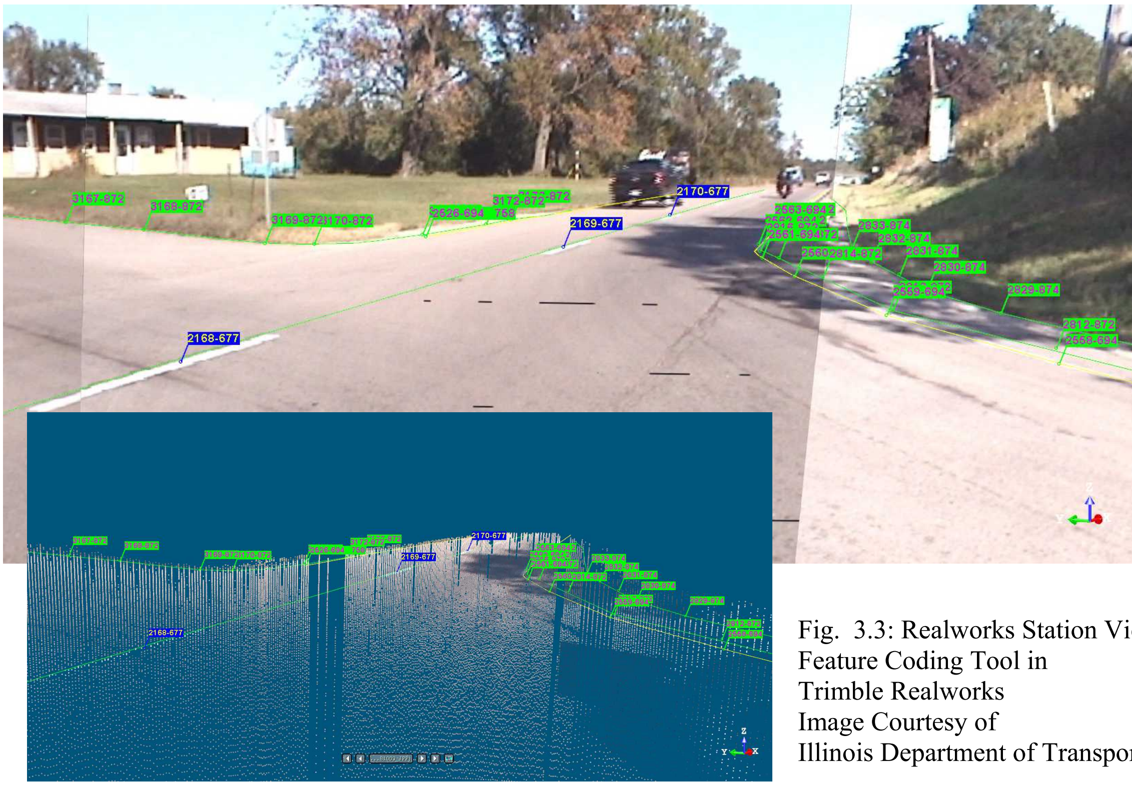

Fig. 3.3: Realworks Station View Feature Coding Tool in Trimble Realworks
Image Courtesy of
Illinois Department of Transportation.

Edge detection is a weakness. Exact edges are hard to determine. Image orientation with the point cloud will be necessary to enhance edge detection.

Survey coding may not be necessary if the line work required can be generated automatically on the levels and/or layers required by transportation officials. Mobile survey data is traditionally delivered in a computer aided drafting (CAD) format such as Microstation or AutoCAD.

3.2.4.2. Mobile GIS Asset Collection

Roadway asset collection is currently the leading use of this collection method. Higher collection speeds can be used since the data is sparser than a typical survey, accuracy is less important, and one pass is usually all that is needed to collect sufficient data. Assets can be automatically extracted from photogrammetric methods and/or LiDAR features. See Figure 3.4 below for an example of software that performs such extraction.

This data is then compiled into a database for use in a GIS system.

Asset data is traditionally delivered in a GIS and/or database format such as a shapefile or geodatabase. See Table 3.1 for a list of asset classes and features.

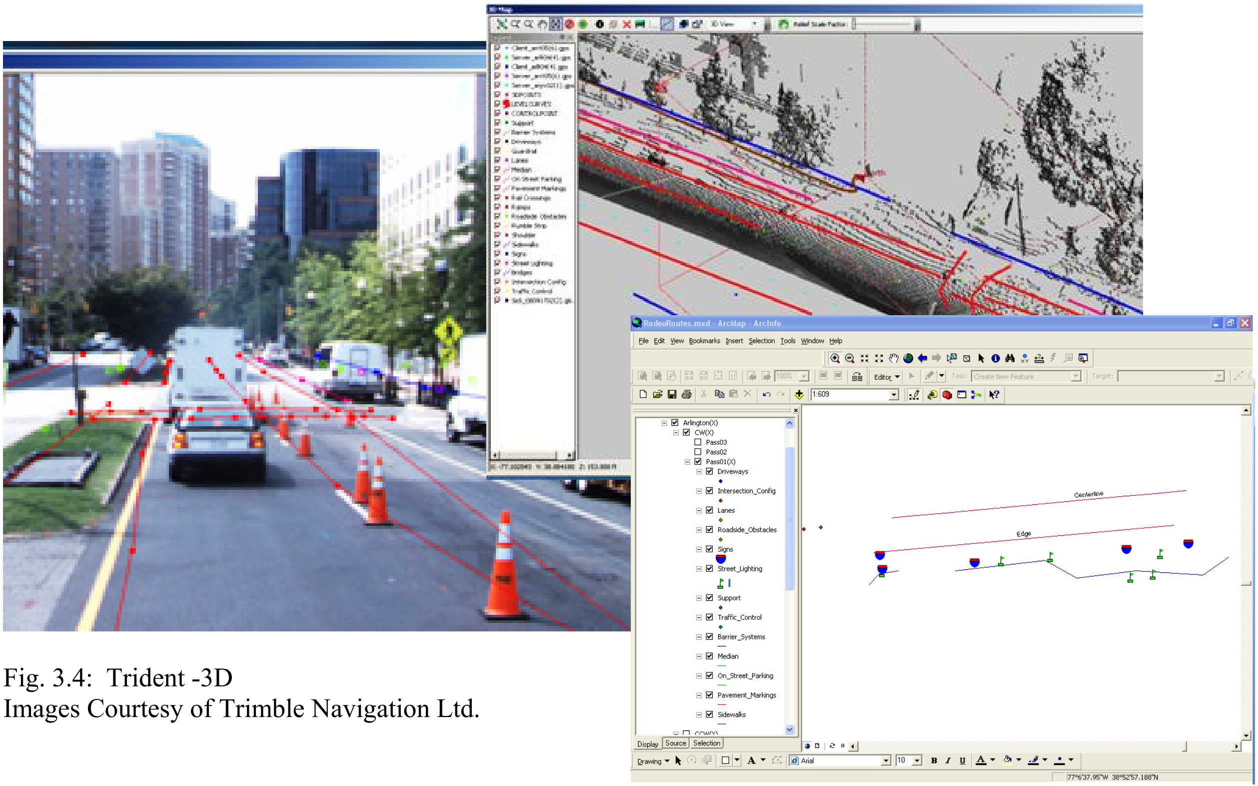

Fig. 3.4: Trident -3D
Images Courtesy of Trimble Navigation Ltd.

3.2.4.3. Mobile Pavement Inspection

Pavement inspection is a more intense data collection than roadway asset collection. More detail is needed and at greater relative accuracies. Some of the data collected is pavement edge, profile, skid characteristics, crack detection, and international roughness index (IRI). See Table 3.1 for a list of collection features.

The speed of collection has recently caught up with asset collection speeds. This opens the door for convergence of the collection of both data sets at the same time. However, the collection frequency, accuracy, and resolution may not be the same. The users of roadway asset data may need data to be collected more often than pavement inspection data. In some cases the opposite may be necessary. Safety items such as street signs may need to be collected frequently. Roadway geometry may not change very often and not need to be collected frequently. Pavement inspection requires close range imagery and/or high resolution of LiDAR. GIS/Asset collection can be performed with medium range imagery and medium resolution of LiDAR. Convergence of the data collection is possible, but consideration should be given to the sensor configurations and utilization of the more expensive equipment.

Asset data is traditionally delivered in a GIS and/or database format such as a shapefile or geodatabase.

3.3. Complimentary Data Collection

Utilizing aerial and terrestrial together can produce an economical and practical solution for transportation projects. Aerial and terrestrial collection methods are very similar. Both require a vehicle for transportation of the sensors and careful acquisition planning. Aerial and terrestrial both require ground control for positioning, orientation, and quality control. Both require post processing of GNSS/IMU data for georeferencing and sensor orientation. Aerial methodology has been transferred to terrestrial data collectors.

The operation costs of operating a van is much less than an airplane. The aerial collection is a rapid collection of a wider corridor than terrestrial. However, it has fewer points per square meter and is less accurate. Terrestrial collection provides greater point density and better accuracy than aerial. The following is a list of speed, point density, and accuracy of aerial and terrestrial collection methods.

Table 3.2: Collection Speed Matrix.

Collection Matrix			
	Speed	**Point Density**	**Accuracy**
1	Aerial	Tripod Laser	Survey
2	Mobile Mapping	Mobile Mapping	Tripod Laser
3	Tripod Laser	Aerial	Mobile Mapping
4	GIS/Map	Survey	Aerial
5	Survey	GIS/Map	GIS/Map

The general orientation of the views of aerial and terrestrial complement each other. Aerial traditionally provides a NADIR view and terrestrial provides a ground level oblique view. These complimentary methods therefore enable the extraction of features that are oriented both horizontally and vertically. Mobile GIS Asset collection provides the vertical roadway asset features such as signs that aerial cannot collect and is a much more rapid collection than traditional GIS Asset Mapping. Mobile pavement inspection provides some road characteristics that the other collection methods do not obtain. Mobile survey may provide enough road characteristics such as roadway geometry and some assets could be collected without complete pavement inspection.

Utilizing the terrestrial collection for edge of shoulder to edge of shoulder, and aerial collection for everything outside of this area provides an economical and practical solution for surveying.

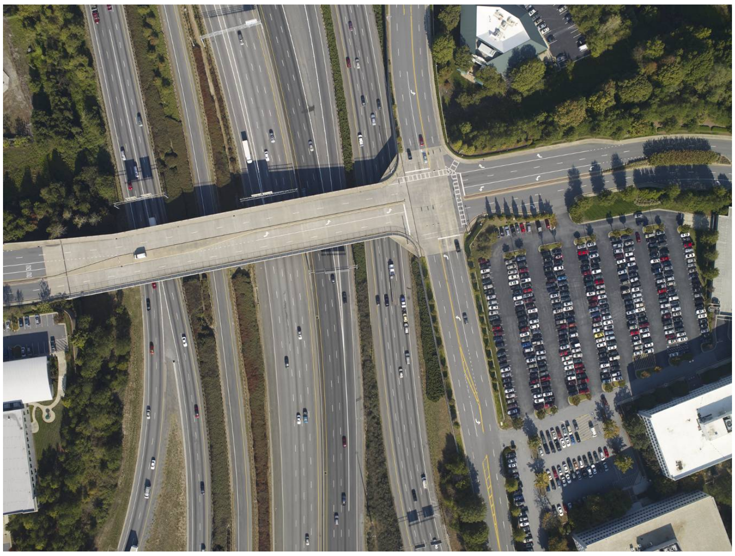

Fig: 3.5: Aerial Photo of Right-of-Way.

The greater point density and accuracy of the terrestrial collection allow for design level data. The wider corridor collection of the aerial allows for drainage design and planning that does not require greater point density and accuracy. The two methods combined with proper planning can save money and time over traditional methods. Figure 3.6 below is an example of a combined aerial and terrestrial LiDAR data set.

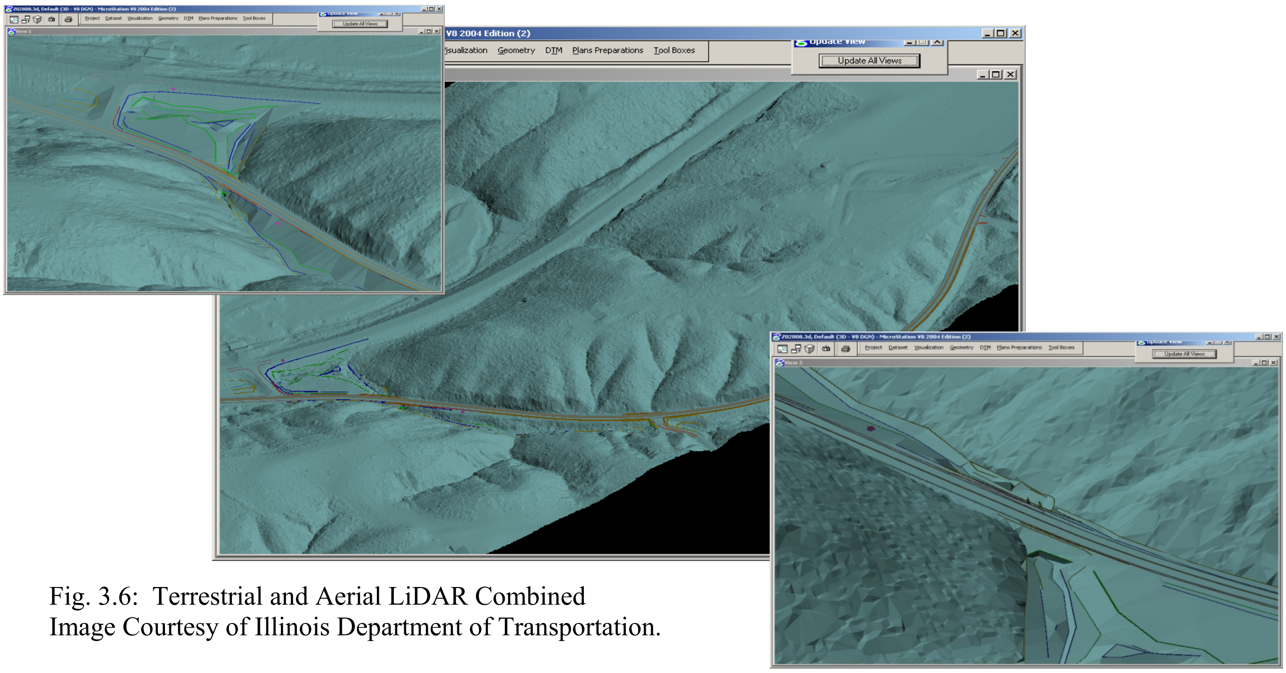

Fig. 3.6: Terrestrial and Aerial LiDAR Combined
Image Courtesy of Illinois Department of Transportation.

The two methods combined provide for practical and economic solutions depending on the phase of the project and the needs of the user in the roadway life cycle. Aerial collection is usually performed in the planning stage and may involve a wider corridor if alternatives are being investigated. Terrestrial collection can be performed in the remaining stages of the roadway life cycle. Redundant data can be useful in georeferencing data together and quality control checks. Aerial and terrestrial collection methods contribute to the creation of a common model. They each provide their own unique advantages with collection speed, required accuracy, collection density, views, and safety.

4. SOFTWARE

The hardware involved in today's advanced data collection is progressing faster than the software. There is not any software or platform that is designed to handle all the different kinds of data throughout the roadway life cycle. The collection of data at different phases of the life cycle has distinct requirements. Open standards for a 3D model must become reality for the data to converge.

Software is as diverse as the data is distinct throughout the life cycle. The platform for deliverables on most transportation projects revolve around Computer Aided Drafting (CAD) format and Geographic Information System (GIS) format. Aerial deliverables are typically delivered in the CAD format. Survey deliverables are also CAD format. Roadway asset and pavement inspection deliverables are typically delivered in a GIS format. There exists a paradigm that all this data can't be part of one model. This paradigm must shift to move forward with significant gains in usability, reliability, cost, and schedule.

Users must be able to access the data they need from a common source model. Standards need to be put in place for integrated sharing of data. The most stringent needs for a specific user should be thought of regardless of the current users needs. The data collector should realize that anyone throughout the life cycle may need to use this data. For example, a designer may not need to know what kind of tree a tree is, but an environmentalist in the planning phase may need to know. The probability of future usage should be considered. However, collecting all the data at one time could produce significant savings over multiple trips to the field at different times in the life cycle. The rapid collection methods and orders of magnitude cost savings will make this all inclusive collection become reality.

Updates should be the only remaining item after time passes from the original collection. Improvements to change detection will make updating information much easier. Change detection can be used from satellite or aerial imagery to detect where major changes have occurred so that the collector can focus on only what needs to be updated. Similar detection could be possible with the point cloud data. Changes in point clouds could be recognized and a more detailed survey could be required.

Aerial LiDAR data that may not be reliable enough to count on may become more usable by integrating other data collection. LiDAR collection depends on patterns of the points. Most filtering software uses routines that look for common planes or slopes to filter out anomalies in the data. This can provide some confidence that a point is on the surface that the users believes it to be on. However, it cannot guarantee it. The use of other data from the 3D model may provide further confidence. Using mobile LiDAR data and/or survey data could provide clues or identifiers as to the correct surface of the aerial LiDAR data. Images with a table of related LiDAR intensities could indicate further confidence in the surface. As color aerial LiDAR collection becomes more common, the image colors can become an identifier of the correct surface.

Software that can utilize geometry patterns more specific to roadway data can be developed to identify and/or create breaklines, topographic features, specific mass points, and edges. Edge detection is the most sought after solution for aerial and terrestrial LiDAR collections.

5. CONCLUSION

The author’s intent has been to generate thought about data convergence of aerial and terrestrial data and what it will take to bring this to fruition. The gains made by the advanced data collection methods will not be realized until there is an open source 3D model that can be used by all stakeholders in a roadway life cycle. Synergy can be realized from the integration of aerial and terrestrial data on transportation projects. Transportation projects are well defined in scope and standards. This definition provides the platform for data convergence.

Intelligent transportation systems will need a complete 3D model to be implemented. Common models need to be consistent between states, provinces, countries, and continents. This does not mean each entity cannot have different standards. It suggests the model should be open source and accommodate the diversity of standards.

The convergence of the data has barriers that need to be considered. Permanent, semi-permanent, and object control points on one single horizontal and vertical datum must become common throughout the roadway life cycle. The strengths and weaknesses of aerial and terrestrial data need practical evaluation to collect the core data and attributes for all users of the data throughout the roadway life cycle. Integrated application of aerial and terrestrial data that create economic solutions need to be considered. Software tools need to be created that can analyze and merge data from multiple sources. Enterprise solutions need to control the data from collection to use. This solution should make the data reliable and make the data readily available for all users throughout the roadway life cycle.

The differences between the aerial and terrestrial collection methods have not eliminated the use of any single solution. The similarity between the sensors used are creating knowledgeable users for either aerial or terrestrial data collection and processing. Aerial and terrestrial data are becoming more complimentary than competitive. Transportation projects provide a great opportunity to take advantage of aerial and terrestrial data integration.