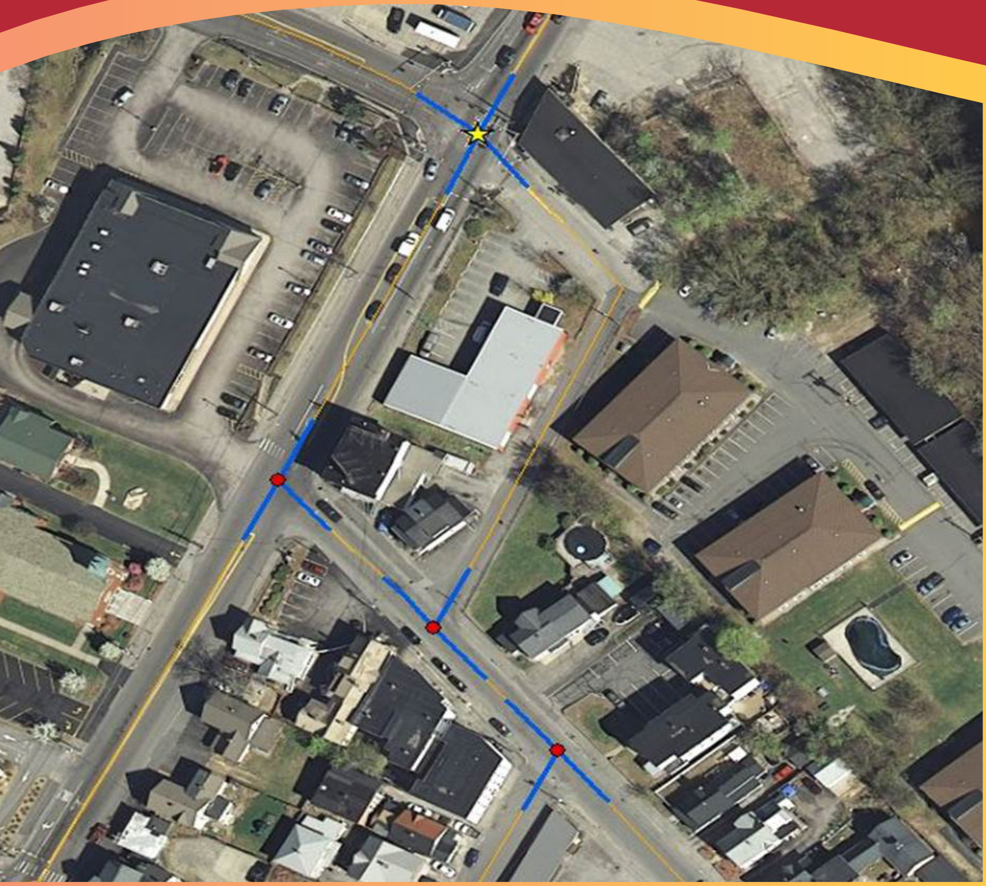
MIRE MIS Lead Agency Data Collection Report



MIRE
MODEL INVENTORY OF ROADWAY ELEMENTS
Dictionary of Roadway Data Elements for Safety

FHWA Safety Program

U.S. Department of Transportation
Federal Highway Administration

Safe Roads for a Safer Future
Investment in roadway safety saves lives

http://safety.fhwa.dot.gov

FOREWORD

The Federal Highway Administration's (FHWA's) Highway Safety Improvement Program (HSIP) is a data driven program that relies on crash, roadway, and traffic data for States to conduct effective analyses for problem identification and evaluation. The FHWA developed the Model Inventory of Roadway Elements (MIRE) to provide a recommended listing and data dictionary of roadway and traffic data elements critical to supporting highway safety management programs. MIRE is intended to help support the States' HSIPs and other safety programs.

The MIRE Management Information System (MIRE MIS) was a project to explore better means of collecting MIRE data elements, using and integrating MIRE data, and identifying optimal data file structures. The resulting products include a report documenting potential means of collecting MIRE data, a MIRE Guidebook on the collection of MIRE, a suggested MIRE data file structure report, and a report on Performance Measures to Assess Quality that will assist the States in conducting a more effective safety program. The intent of the MIRE MIS project was the integration of MIRE into States' safety management processes.

The *MIRE MIS Lead Agency Data Collection Report* is one of the products of the MIRE MIS effort. This report presents the findings from an effort to assist two States to expand their roadway inventory data collection to include MIRE intersection data elements for use in advanced analytic methods. The report documents two different methods of data extraction that were used by the pilot states. The implications from this effort may lead to more effective and efficient methods of increasing the collection and use of MIRE by State and local transportation agencies. Further, these results may better assist States in complying with the guidance and requirements of the Moving Ahead for Progress in the 21st Century (MAP-21) legislation.

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Notice

Quality Assurance Statement

TECHNICAL DOCUMENTATION PAGE

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16. Abstract
The Federal Highway Administration (FHWA) developed the Model Inventory of Roadway Elements (MIRE) as a listing of roadway features and traffic volume elements important to safety management to help support agencies move towards more data-driven decision-making. The purpose of this effort was to test the feasibility of collecting MIRE data through a Lead Agency Program as part of the MIRE Management Information System (MIRE MIS) project. FHWA chose two lead agencies, New Hampshire and Washington State. Both agencies requested support for collecting intersection elements. This report documents the effort to develop an intersection inventory for each Lead Agency, including development of the data collection tools, the challenges faced, and the lessons learned. These lessons are applicable to other agencies interested in improving their roadway inventory data to support their safety programs through data-driven decision-making.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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ACRONYMS

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
CRAB	County Road Administration Board
DMI	Distance Measuring Instrument
FAQ	Frequently Asked Questions
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
HOV	High Occupancy Vehicle
HPMS	Highway Performance Monitoring System
HSIS	Highway Safety Information System
HSM	Highway Safety Manual
IDE	Integrated Development Environment
IHSDM	Interactive Highway Safety Design Model
KML	Keyhole Markup Language
LRS	Linear Referencing System
MIDS	MIRE Intersection Data Survey
MIRE	Model Inventory of Roadway Elements
MIS	Management Information System
NHDOT	New Hampshire Department of Transportation
QA/QC	Quality Assurance/Quality Control
RPC	Regional Planning Commission
RSDP	Roadway Safety Data Program
SIMMS	Signals Maintenance Management System
SQL	Structured Query Language
TMC	Turning Movement Count
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

Quality data are the foundation for making important decisions regarding the design, operation, and safety of roadways. With the recent development of more advanced safety analysis tools, such as the *Highway Safety Manual* (HSM) *(1)*, the *Interactive Highway Safety Design Model* (IHSDM) *(2)*, and *SafetyAnalyst (3)*, many agencies are seeing the value of better roadway data. The more information a State or local agency has about its roadways, the better it can use resources to effectively and efficiently identify problem locations, diagnose the issues, prescribe appropriate countermeasures, and evaluate the effectiveness of those countermeasures. This can lead to a more successful safety program supported by data-driven decision-making to help improve the safety of roadways and ultimately save lives.

The Federal Highway Administration (FHWA) developed the Model Inventory of Roadway Elements (MIRE) as a listing of roadway features and traffic volume elements important to safety management to help support agencies with data-driven decision-making. A critical step toward the acceptance and implementation of MIRE is the conversion of MIRE (which is now a listing of variables) into a management information system (MIS). FHWA undertook the MIRE MIS project to assist States in developing and integrating MIRE into an MIS structure that will provide greater utility in collecting, maintaining, and using MIRE data.

The MIRE MIS project included the exploration, development, and documentation of the following:

- Mechanisms for data collection.
- An efficient process for data handling and storage.
- Development of a data file structure.
- Methods to assure the integration of MIRE data with crash and other data types.
- Performance measures to assess and assure MIRE data quality and MIS performance.

This report summarizes the MIRE MIS effort to test the feasibility of collecting MIRE data through a Lead Agency Program. The objective of the Lead Agency Program was to assist volunteer transportation agencies to collect, store, and maintain MIRE data, and to incorporate those data into their safety programs. Using an application process, FHWA chose the New Hampshire Department of Transportation (NHDOT) and the Washington State Department of Transportation (WSDOT) as Lead Agencies to participate in the MIRE MIS effort. A second objective of this effort determined the level of effort and resources necessary to achieve these goals.

Both NHDOT and WSDOT requested an intersection inventory for use in *SafetyAnalyst*, but with slightly different variables. Having both agencies select similar elements provided the project team with an opportunity to compare different data collection methodologies. The project team developed two different tools to collect these data, one simplified tool based on a geographic information system (GIS) platform (for NHDOT), and one more sophisticated tool based on proprietary software (for WSDOT).

Both data collection efforts presented similar lessons learned, including:

- MIRE flexibility: The primary goal of this effort was to test the feasibility of collecting MIRE data elements. Both NHDOT and WSDOT requested an intersection dataset to import and use in *SafetyAnalyst*. The project team developed data collection tools to populate a database to meet that goal. While the data elements selected were based on MIRE, the data collected required deviations from the MIRE data dictionary in order to tailor them for *SafetyAnalyst*. The flexibility allowed the resulting dataset to best meet the needs of the individual agencies.

- Development of the Work Plan: The work plan provided a clear vision and approach for conducting the data collection. Developing the work plan at the onset of the project helped identify clear expectations on the part of the States and the project team.

- Constant contact/feedback between the contractor and the State DOT: Throughout the entire process, both transportation agencies made themselves available to answer any questions and to provide clarification and feedback. This constant communication was key to developing a dataset that best met each agency's needs.

- Use of the sample dataset: The project team provided a sample dataset to both agencies to ensure there were no problems with the data. This allowed the agencies to identify any potential issues and the project team time to correct them before completing the data collection rather than having to go back and correct the data—thus saving valuable time, budget, and resources.

- Use of existing data: The project team derived many of the basic intersection inventory elements from existing data sources, thereby reducing the time needed for data collection.

There were also differences in the two data collection efforts, primarily as a result of the data collection tools each agency used. The NHDOT tool took less time to develop, but did not have as many built-in tools. The tool developed for WSDOT featured more built-in capabilities for identification and extraction of elements, including tracking collection progress; however, the WSDOT tool took more time and resources to develop than the NHDOT tool.

Ultimately, the effort to develop an intersection inventory, data collection tools, determine the implications of the differences in the tools, the challenges faced, and the lessons learned, are all important information for agencies interested in developing roadway inventories. This information can help improve their roadway inventories to better support data-driven decision-making, improve the safety of roadways, and most importantly, save lives.

INTRODUCTION

Quality data are the foundation for making informed decisions regarding the design, operation, and safety of roadways. With the recent development of more advanced safety analysis tools, such as *Highway Safety Manual* (HSM) *(1)*, the *Interactive Highway Safety Design Model* (IHSDM) *(2)*, and *SafetyAnalyst (3)*, many agencies are recognizing the value of better roadway data. The more information a State or local agency has about its roadways, the better it can use its resources to effectively and efficiently identify problem locations, diagnose issues, prescribe appropriate countermeasures, and evaluate the effectiveness of those countermeasures. This process can lead to a more successful safety program supported by data-driven decision-making to help improve the safety of roadways and ultimately save lives.

To help support States improve their roadway data, the Federal Highway Administration (FHWA) Office of Safety created the Roadway Safety Data Program (RSDP). This program encompasses a variety of initiatives with the goal of improving the collection, analysis, management, and expansion of roadway data for safety *(4)*. One initiative under the RSDP umbrella is the Model Inventory of Roadway Elements (MIRE). MIRE is a guideline that provides a listing of roadway features and traffic volume elements important to safety management, and includes standardized coding for each element. MIRE Version 1.0 currently includes 202 elements grouped into three categories: roadway segments, roadway alignments, and roadway junctions *(5)*.

A critical step toward the acceptance and implementation of MIRE is the conversion of MIRE into a management information system (MIS). FHWA undertook the MIRE MIS project to assist States in the development and integration of MIRE into an MIS structure that will provide greater utility in collecting, maintaining, and using MIRE data.

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This report summarizes the MIRE MIS effort to test the feasibility of collecting MIRE data through a Lead Agency Program. The objective of the Lead Agency Program was to assist volunteer transportation agencies to collect, store, and maintain MIRE data, and to incorporate those data into their safety programs. FHWA chose the New Hampshire Department of Transportation (NHDOT) and the Washington State Department of Transportation (WSDOT) through an application process to participate as lead agencies. A second objective was to determine the level of effort and resources necessary to achieve these goals.

FHWA did not anticipate that one agency would collect all 202 elements but that each Lead Agency would collect either all critical elements in one subsection of MIRE (e.g., intersection elements, ramp elements, curve elements, pedestrian elements, etc.), or critical elements from a combination of subsections. Each Lead Agency chose the MIRE elements they wanted to collect through the program. Both NHDOT and WSDOT requested the collection of many critical intersection elements to expand their intersection inventories for use in *SafetyAnalyst*. *SafetyAnalyst* is a software tool used by State and local highway agencies for highway safety management. FHWA developed *SafetyAnalyst* through a transportation pooled fund study, a cooperative effort between States and local agencies. It is now available through the American Association of State Highway and Transportation Officials (AASHTO). It is important to note that the effort documented in this report is applicable to any agency interested in developing an intersection inventory, independent of the safety analysis tool(s) used by the agency. WSDOT also hopes to include their intersection inventory in the Highway Safety Information System (HSIS) database.

Having both agencies select similar elements provided an opportunity to compare different data collection methodologies. The project team developed two different tools to collect intersection data: a simplified tool based on a geographic information system (GIS) platform for NHDOT, and a more sophisticated tool based on proprietary software for WSDOT. This report documents the effort to develop an intersection inventory, including development of the data collection tools, identification of the implications of the differences in the tools, the challenges faced, and the lessons learned that could assist other agencies interested in undertaking a similar effort.

NEW HAMPSHIRE

The starting point for NHDOT was the MIRE listing. NHDOT reviewed the MIRE elements as part of the application process and provided a list of the elements they would like to have included in the intersection inventory. The elements chosen included all of the required, and some of the optional, *SafetyAnalyst* elements for intersections. Table 1 shows the elements NHDOT requested for the overall intersection and each intersection leg. These elements consist of location, operations, geometric, and traffic count data.

While NHDOT would ultimately like to have detailed information on all intersections on public roads within the State, there was a limited budget available for the collection of data. NHDOT prioritized its intersections based on ownership of the intersecting roadways. NHDOT's top priority was the State/State intersections (approximately 1,500), followed by the State/local intersections (approximately 8,800), and then local/local intersections (approximately 30,750). Based on the available funding, NHDOT requested that the project team focus on collecting data at State/State and State/local intersections. This group totaled 10,300 intersections for inclusion in the intersection inventory.

Table 1. Intersection inventory elements requested by NHDOT.

Intersection Elements	Intersection Leg Elements
Intersection ID	Intersection ID
Location System	Leg ID
Route Type	Type
Route Name	Location System
County	Route Type
Major Road MP	Route Name
Minor Road Location System	County
Minor Road Route Type	Milepost/Distance
Minor Road Route Name	Influence Zone
Minor Route MP	Direction of Leg
Agency Site Subtype	Thru Lanes
GIS Identifier	Left Turn Lanes
Major Road Name	Right Turn Lanes
Minor Road Name	Median Type
Major Road Direction	Left Turn Phasing
Begin Influence Zone (Major & Minor)	Speed Limit
End Influence Zone (Major & Minor)	Turn Prohibitions
District	Operations
City Town	Approach Volume
Jurisdiction	Right Turning Movement Count
Area Type	Thru Turning Movement Count
Intersection Type	Left Turning Movement Count
Traffic Control Type	
Offset Intersection	
Offset Distance	
Growth Factor	
Date Open to Traffic	
Corridor	
Major Road Annual Average Daily Traffic (AADT)	
Minor Road AADT	
Comment	

Methodology

Once the NHDOT and the project team established the elements to include in the intersection inventory, the project team developed the intersection inventory using the following 12 steps:

1. Determine what data elements are already collected and what remaining data need to be collected.
2. Determine how the existing data are currently collected, the available data sources, and how to collect the remaining needed data.
3. Develop a detailed work plan.
4. Develop or expand the intersection node layer.
5. Develop a model for extracting existing data to pre-populate the intersection inventory.
6. Develop the data collection interface and toolbar.
7. Collect the data.
8. Provide a sample dataset to NHDOT.
9. Conduct quality assurance/quality control (QA/QC) reviews.
10. Conduct field verification of data elements.
11. Develop the traffic volume database.
12. Integrate the new dataset into the current system.

The following sections provide an overview of each of these steps.

Step 1: Determine Existing Data and Remaining Data Needs

The project team first identified the elements NHDOT wanted included in the inventory that NHDOT had already collected in some form. Prior to the initiation of the Lead Agency Program, NHDOT participated in the FHWA Capabilities Assessment *(6)*. The assessment questionnaire included a table of all of the MIRE elements, documenting which elements NHDOT collected and in what datasets they are stored. NHDOT gave the project team permission to use the information in the questionnaire as a starting point. Over a series of onsite meetings, the project team worked with the NHDOT safety, roadway inventory, and GIS staff to review their data collection practices and datasets.

During the review of the information in the Capabilities Assessment questionnaire and in discussion with NHDOT staff, the project team discovered that it was not as straightforward as simply having the data element, or not having the data element. The project team determined that there were various categories of data availability:

- *Exist*: The data element exists exactly as it is defined.
- *Derive*: The data element exists in another format and needs to be transformed from the current format or gathered from existing GIS layers. This value may need to be further validated.
- *Assign*: The data element does not exist, but the value can be derived using guidance or coded values provided by NHDOT.
- *Collect*: The data do not exist and will need to be collected.

Step 2: Determine How Data are Collected or will be Collected

Conducted concurrently with Step 1, the project team worked with NHDOT to determine how it currently collects and stores the existing data. The three primary sources of existing roadway data at NHDOT are GIS layers, roadway videolog, and the data required for the FHWA Highway Performance Monitoring System (HPMS).

Currently, NHDOT stores its roadway and intersection data in a statewide road inventory database that is maintained using ESRI ArcGIS version 9.x software. The inventory is a node-based model containing road centerlines and intersections for all Federal, State-maintained, local, and private roads. (This will be described in greater detail in subsequent sections.) The database evolved from NHDOT's straight-line diagrams that it previously used to maintain the State's official road mileage for use in HPMS reporting and Highway Block Grant Funding.

In the early 2000s, NHDOT contracted with a private company to update all of the State-maintained roadways in New Hampshire. This involved driving each State-maintained road and recording the mileage using a distance measuring instrument (DMI). The remaining roads (local and private) were inventoried by the State's nine Regional Planning Commissions (RPCs). At the time of this report, NHDOT maintained the database using high-resolution aerial photographs with supplemental field verification.

NHDOT has over 40 roadway attributes for each road in the database. Each road centerline and intersection node has a unique identifier that allows linkage between the attribute information and the corresponding road segment/intersection. Mileposts identify the length of each road segment, representing the distance between each node or intersection. The road centerline attribute table stores the begin and end mileposts of each road segment. In addition, the road centerline and intersection files use a linear referencing system (LRS) in which each road segment contains distance value measures along the line.

Within the database, the road centerlines are separated into two layers: High Order Routes and Road Anchorsections. The High Order Routes layer represents the entire length of geometry for a route, whereas the Road Anchorsections layer represents the individual road segments (from node to node) that make up a route. NHDOT staff update the road inventory database on a daily basis, with an annual release made available to the public.

NHDOT also obtains roadway information from a videolog system that uses a data collection van. The van includes three cameras for the videolog—front- and rear-facing cameras with a 110-degree field of view and a 360-degree camera mounted on the roof—much like the Google Street View™ vehicles. The van tracks global positioning system (GPS) coordinates of intersections and conducts real-time corrections to the GPS while linked with a GIS map. In addition, NHDOT collects data per the HPMS requirements. There are 27 MIRE data elements that are required for "full extent" collection through HPMS (i.e., data reported on all public roads). The MIRE Version 1.0 report includes a list of the MIRE elements that are collected through HPMS *(5)*.

Based on the information obtained from NHDOT, the project team determined how to populate each intersection element in the inventory based on the categories of data availability discussed in Step 2:

- *Exist*: Use values as they currently exist.
- *Derive*: Transform existing data or gather from GIS layer. These data may require validation during data collection.
- *Assign*: Assign values that are derived using guidance or coded values.
- *Collect*: Collect information that has not yet been collected or validated from GIS, HPMS, or visual imagery. Note the traffic data elements are discussed in further detail under Step 11: *Develop Traffic Volume Database*.

Table 2 identifies each element included in the intersection inventory, the current data source (if applicable), and the method of collection based on its category of availability. Note the traffic data elements are discussed in further detail under Step 11: *Develop Traffic Volume Database*.

Table 2. Elements and primary method of data collection for intersection inventory elements.

Intersection Elements	Intersection Leg Elements
Intersection ID (GIS – exist)	Intersection ID (GIS – exist)
Location System (GIS – assign)	Leg ID (GIS – exist)
Route Type (GIS – derive)	Type (GIS – derive)
Route Name (GIS – exist)	Location System (GIS – assign)
County (GIS – exist)	Route Type (GIS – derive)
Major Road MP (GIS – derive)	Route Name (GIS – exist)
Minor Road Location System (GIS – assign)	County (GIS – exist)
Minor Road Route Type (GIS – derive)	Milepost/Distance (GIS – derive)
Minor Road Route Name (GIS – exist)	Influence Zone (assign)
Minor Route MP (GIS – derive)	Direction of Leg (GIS – derive)
Agency Site Subtype (GIS – assign)	Thru Lanes (HPMS – collect; validate)
GIS Identifier (GIS – exist)	Left Turn Lanes (HPMS – collect; validate)
Major Road Name (GIS – exist)	Right Turn Lanes (HPMS – collect; validate)
Minor Road Name (GIS – exist)	Median Type (HPMS – collect; validate)
Major Road Direction (GIS – derive; validate)	Left Turn Phasing (collect; validate)
Begin Influence Zone (Major & Minor) (assign)	Speed Limit (HPMS –collect; validate)
End Influence Zone (Major & Minor) (assign)	Turn Prohibitions (collect; validate)
District (GIS – derive)	Operations (collect; validate)
City Town (GIS – exist)	Approach Volume (Review existing; GIS – assign; collect)
Jurisdiction (GIS – derive)	Right Turning Movement Count (Review existing; GIS – assign; collect)
Area Type (GIS – derive)	Thru Turning Movement Count (Review existing; GIS – assign; collect)
Intersection Type (GIS – derive; validate)	Left Turning Movement Count (Review existing; GIS – assign; collect)
Traffic Control Type (validate; collect)	Approach Volume (Review existing; GIS – assign; collect)
Offset Intersection (GIS – derive; validate)	
Offset Distance (GIS – derive; validate)	
Growth Factor (NHDOT – assign)	
Date Open to Traffic (NHDOT – exist)	
Corridor (NHDOT – assign)	
Major Road AADT (Review existing; GIS – assign)	
Minor Road AADT (Review existing; GIS – assign)	
Comment (NHDOT – assign, collect)	

Step 3: Develop Detailed Work Plan

The project team next developed a detailed work plan that included a description of NHDOT's existing data system, including sources of available data. It also provided an overview of the proposed effort, including methodology, timeframe, cost, and a detailed data dictionary that NHDOT provided to the project team.

The data dictionary included the intersection inventory elements, their attributes, and important considerations for each element. It was necessary to develop a customized data dictionary rather than using the MIRE data dictionary. NHDOT developed the data dictionary based on *SafetyAnalyst* requirements so the final database could be readily imported into the software. MIRE is guidance intended to be flexible to meet the needs of each agency. While FHWA developed MIRE in part to help support the implementation of *SafetyAnalyst*, it was not the solitary goal. Rather, FHWA developed MIRE to support a variety of data analysis tools. During the development of MIRE Version 1.0, FHWA considered not only the requirements of *SafetyAnalyst*, but also considered the requirements of HPMS requirements and other analysis tools, and also obtained feedback from practitioners garnered through webinars. Therefore, the MIRE element naming conventions and attribute listings do not align exactly with the *SafetyAnalyst* data requirements. The project team adopted the data dictionary NHDOT provided to ensure the resulting dataset best met the intended use of the data.

Step 4: Develop Node Layer

Identification of the location of the intersections proved to be a crucial step in the development of the intersection inventory. NHDOT already had an existing node layer that they developed for use by State and local law enforcement agencies for locating crashes. The State created nodes at intersecting roads where road names or functional classifications changed, and at town limits and county lines. When created, each node has a unique identifier assigned to it. The node layer is maintained using NHDOT's existing road centerline file. Using this node layer as a base, NHDOT then undertook an extensive manual effort to review and locate the State/State and State/local intersections using GIS and aerial photography as part of its effort to implement *SafetyAnalyst*.

The project team identified several issues with this methodology. Most notably, three percent of the nodes were not actual intersections, as defined by NHDOT. The majority of these non-intersections were locations where a Class VI road (unmaintained road subject to bars and gates) intersected with a State road. NHDOT did not want to include these intersections in the intersection inventory.

The project team also expanded the intersection node layer to include local/local intersection node layer as part of this effort. Based on the issues the project team identified with the existing methodology, the team took a different approach to expand the local/local node layer beyond what NHDOT had done to develop the State/State and State/local node layer. The existing node layer consisted of all the start and end points of each roadway segment in the road inventory database. Roads were split at town and county boundaries. To create the local/local intersection layer, the project team filtered the nodes down to actual intersection locations of local/local roads using ESRI ArcGIS 10.0 software to complete all work. The project team's methodology was as follows:

1. Extracted the local roads from the State's road inventory centerline file using a definition query.
2. Used linear referencing tools, specifically the '*Locate Features Along Routes*' tool, to process the State's node layer and extract the local roads from the road inventory centerline file to identify each local road segment that touched a node. The output was a table listing each roadway segment, which included all of the road inventory attributes, coded by the unique identifier of each node and road segment.
3. Added a temporary field to the table created in Step 2 and populated based on road legislative class. Each record in the table was scored based on the legislative class of the road. The project team created another temporary field to further select only the local/local intersections and exclude any node locations that represented the intersection of two private roads. In addition, potential intersection locations were screened to remove intersections of Class VI roads.
4. Used a frequency analysis to summarize the legislative class scoring created in Step 3. The resulting table contained a single record for each node, with the total score of the legislative class information.
5. Used a definition query to remove any potential intersections with a score of "0," which represented private/private intersections and Class VI/Class VI intersections.
6. Completed a final spatial selection using the '*Select by Location*' feature to remove any potential intersections that touch a State route, which eliminated any State/local intersections from the database.

NHDOT's *Legislative Class* attribute in the existing roadway data was used in the development of the intersection node layer. The Legislative Class designates roadway ownership and maintenance responsibility:

- Class I – Primary State highways.
- Class II – Secondary State highways.
- Class III – Limited access recreational roads.
- Class IV – State highways in a designated 'compact section' of cities or towns (e.g., State-owned but locally maintained).
- Class V – Local roads.
- Class VI – Unmaintained roads subject to bars and gates.

This methodology provided a way of using GIS tools to screen the nodes down to local/local intersections without the need for manual interpretation.

Step 5: Develop Model for Extracting Existing Data to Pre-Populate the Intersection Inventory

The project team created a model in ArcGIS to automatically extract and transform where necessary, the data from various existing sources within NHDOT (identified in Steps 2 and 3 of the overall effort). They then applied those data to each intersection to pre-populate the intersection inventory. For this project, the output from the model needed to be formatted specifically for use in *SafetyAnalyst*; however, the data could be formatted for use in any safety analysis tool.

NHDOT had already developed a series of Structured Query Language (SQL) scripts to process their existing GIS road inventory files to create an intersection table for import into *SafetyAnalyst*. SQL is a programming language designed for managing data in relational database management systems. Due to inconsistencies in data structure between the NHDOT road inventory files and *SafetyAnalyst*, it was not possible to directly import NHDOT data into *SafetyAnalyst*. The NHDOT SQL scripts processed the road inventory files to extract existing roadway attribute information based on NHDOT's roadway data dictionary and transform the information so that data inputs matched *SafetyAnalyst*'s import formats. The scripts allowed NHDOT to successfully import much of its State system's inventory data into *SafetyAnalyst*. Using these imported data, NHDOT completed network analyses of the State/State and State/local intersections using the required *SafetyAnalyst* data elements.

Although the SQL scripts helped automate the process, some limitations exist with their current methodology. Due to limitations in time and accuracy of some source data, several elements that the State could have collected from existing data were not included in their scripting. These data included mostly elements that the State would have to collect or verify using aerial imagery or roadway videolog, such as intersection offset distance, intersection type, and traffic control type. The State could have derived some elements, such as skew angle and school zones, but these were not required for analysis. In addition, the SQL scripts ran in Oracle SQL Developer, which does not run within the GIS environment. As with any well-maintained GIS, the NHDOT Planning Bureau regularly updates its road inventory database, and, thus, the State should be able to update the *SafetyAnalyst* intersection tables to reflect those changes. Due to the limitations and time requirements of their current process, NHDOT was in need of a more efficient model.

Using ESRI ModelBuilder™ software for ArcGIS 10, the project team developed an ArcGIS Toolbox containing a series of geoprocessing models that process the State's roadway inventory files and generate additional information required by *SafetyAnalyst* that is currently not available within the roadway inventory database. The project team developed the processes within the models from the steps outlined in the SQL scripts originally developed by NHDOT.

In several instances, the project team modified the models to make use of existing GIS functions rather than custom coding.

Currently, the toolbox contains an *Intersection Update Model*, and a *New Intersection Model*. The Update Model checks the most up-to-date road inventory database and updates the intersection inventory tables for any changes to the database. The New Intersection Model allows the GIS user to identify locations of new intersections. New intersections are intersections where the State has accepted a private road as a public road, a new public road has been constructed, or where an intersection has been realigned. The key features contained within the model include:

- Identification of the major/minor road associated at each intersection based on AADT. Populates the road names of each major/minor road, along with its unique segment identifiers.
- Population of the road route type (i.e., Interstate, U.S. route, State route, local road) of each road segment.
- Calculation of the milepost location of each intersection referenced to the State's road inventory database.
- Calculation of the approach direction of each roadway segment of the intersection.
- Identification of the number of legs present at each intersection.
- Calculation of the intersection type (e.g., tee, four-leg, multi-leg, etc.).
- Identification of the city/town, county, NHDOT Maintenance District, State Trooper District, and RPC for each intersection.

The previous import process took several days to complete using NHDOT's original SQL scripts. By using the geoprocessing models the project team developed, the team successfully completed this task in less than one hour. In addition to the significant time savings, the geoprocessing models also provided a GIS user-friendly environment and were conducive to more effective troubleshooting should potential issues arise.

Step 6: Develop Data Collection Interface and Toolbar

The project team used the model described above to pre-populate the intersection inventory with the existing data, and developed a tool to collect the remaining data elements. It was not within the scope to collect data for over 10,000 intersections in the field, so the project team used an alternate methodology to collect the data. The team developed an ESRI GIS-based system to populate the intersection inventory that employed both automated and manual methods.

GIS Database Assessment and Setup

The project team requested and obtained from NHDOT a current version of its GIS database. Since NHDOT uses Oracle as the platform for its ArcSDE geodatabase, the State exported their data into a geodatabase file. The project team then imported the feature classes in the file geodatabase into a SQL Server ArcSDE® geodatabase. The processes were performed in ArcCatalog™ with an ArcEditor™ (standard) or ArcInfo® (advanced) software license. These functions would not be capable with the ArcView® (basic) license.

Once the project team imported the data into ArcSDE®, a team analyst conducted a database assessment, which involved the following steps:

1. Confirmed that all necessary fields for the data collection were present in the feature classes and named correctly. Created new fields, when necessary.

2. Verified that the required fields were in the correct data type (e.g., integer, text, etc.) and length, referencing the *SafetyAnalyst Data Import Reference* document. Corrected field types, if necessary.

3. Set up domains, where necessary, to make sure the data collection proceeded in a consistent manner and in the correct format for use with *SafetyAnalyst*. Used the *SafetyAnalyst Data Import Reference* document as a guide.

4. Verified that the feature classes required for the model and the GIS interface were accounted for and in the proper GIS format.

5. Created the intersection leg feature class from the existing roads layer. The length of the leg did not matter.

Convert the Existing SQL Scripts into ESRI® ModelBuilder™

Once the model pre-populated the intersection and intersection leg feature classes from the roadway inventory datasets, the project team exported the files for use in populating the remaining required *SafetyAnalyst* attributes.

Develop Data Collection Interface and Toolbar

The project team developed an interface to allow for data entry from the videolog and online mapping sources, such as Google and Microsoft Bing®. ESRI's ArcGIS® 10 was the platform used for the interface. The project team also conducted the model and data editing (attribute and feature) within the ArcGIS® 10 desktop environment.

An overview of the GIS interface task included the following subtasks:

- **Design/review of the database**: This phase included an assessment of the data as it currently exists so the project team could correctly set up the data for use in the GIS interface.
    - Exported data from the file geodatabase provided by NHDOT to ArcSDE®.
    - Added fields to feature classes (intersections and legs).
    - Set up domains. Used the *SafetyAnalyst Data Import Reference* document as a guide.
- **Development of data entry forms**: The project team created data entry forms to enter remaining attributes not populated by Model Builder, and to allow the user to edit any existing attributes.
    - Created data entry form for intersections.
    - Created data entry form for legs.
- **Creation of a toolbar that includes several custom tools**: This phase involved creating a custom toolbar that included the model and interface the project team developed in the previous steps. The toolbar contains buttons that perform each of the following functions:
    - Run Model.
    - Edit Attributes of a feature (shows custom data entry forms).
    - Export intersection and leg attribute tables for use in *SafetyAnalyst.*

The project team developed a custom data entry form that allows the user to enter the required MIRE attributes for intersection and leg features. A third party software developer assisted with the development of the form. The form features built-in checks and validations to ensure that all attributes are accounted for. A drop-down menu includes all attributes that have a domain in order to collect the data in a consistent and accurate manner for use with *SafetyAnalyst.* Appendix A provides more detailed descriptions of these built-in checks. Several attributes that NHDOT requested to be collected were outside the scope of this project. The project team included these elements in the data entry interface for future use by NHDOT. For these attributes, a domain was assigned based on the list of attributes provided by NHDOT; however, the project team did not collect those data elements.

The project team created one data entry form for intersection attributes and one form for intersection leg attributes, as shown in Figure 1. The elements shown in light gray text, e.g. Minor Road Route Type, are elements that the project team pre-populated using the model; these did not require any additional action. A designated list of attributes can be chosen from in the drop-down menus using black text, e.g. Intersection Type 1. The empty white boxes shown are points that require data entry, e.g. Number of Left Turn Lanes. The gray boxes with no text, e.g. Lighting Presence and Pedestrian Volume, are placeholders for attributes that NHDOT might collect at a later date.

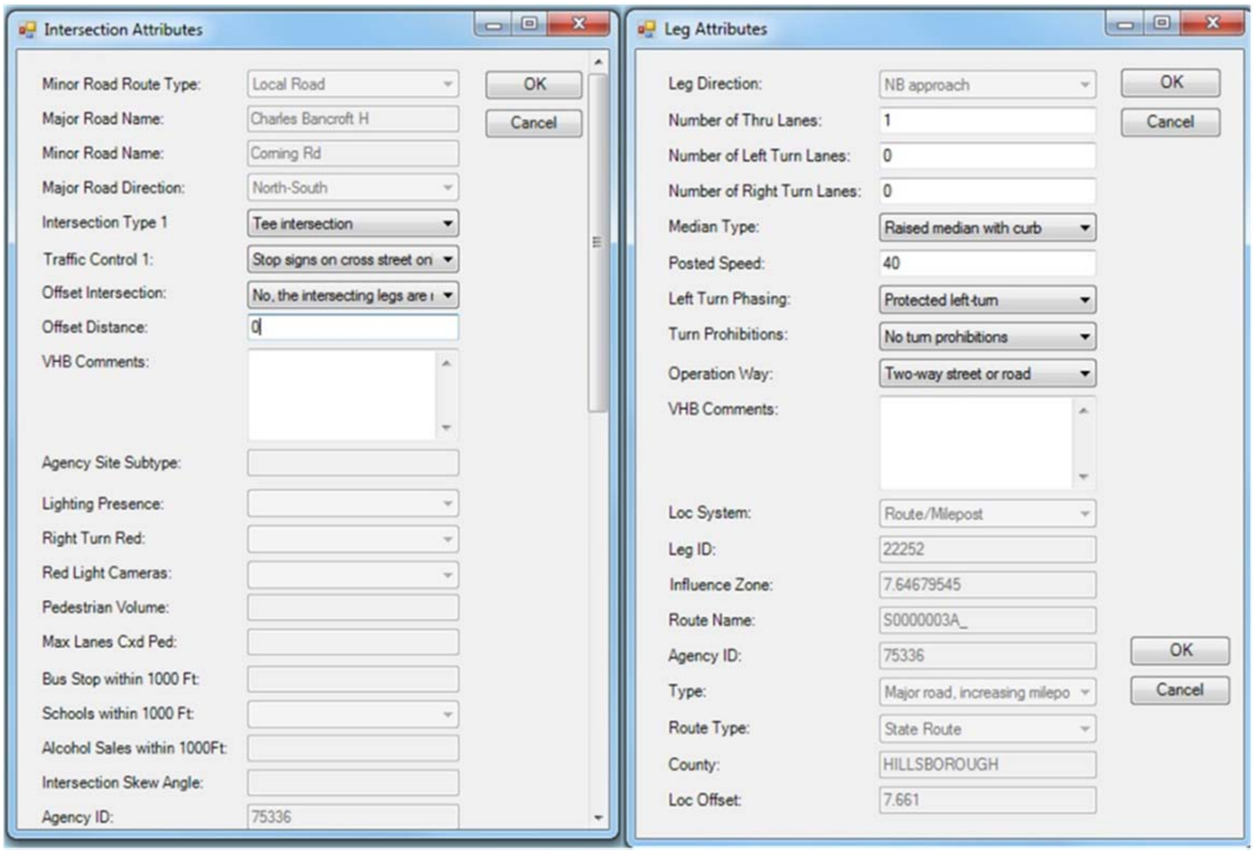


Figure 1. Data entry interface for overall intersection (left) and each leg (right).

The initial intent was to link the videolog with the data collection tool. However, the videolog was not compatible with the software. After working directly with the videolog vendor to find a solution to satisfy the needs of the tool and users, the project team determined that the videolog could not connect with the data collection tool automatically and the requirement of an automatic connection was too cumbersome for its use.

Instead of using the videolog, the project team used the Google Street View™ and Microsoft Bing® Bird's Eye plug-ins for ArcGIS® *(7)*. These add-ins allowed the user to click anywhere on their map in ArcGIS® to bring up a small window with that location in Google or Microsoft Bing®. These tools aided in the data entry process by allowing the users to see fairly current aerial imagery and other base data to help determine the attributes of an intersection or leg. Using these tools also reduced the data entry time since manually searching for the visual image of the intersection was no longer required. This process was the primary substitute for the videolog, but the videolog could still be used as a resource if the imagery from Google or Microsoft Bing® did not provide the information needed. However, it was not an automatic connection and required manually locating the intersections in the videolog.

Step 7: Collect Data

Collecting the data required the installation of the data collection tool on each work station and completion of a two-day training session for the data entry clerks. As part of the training, the project team developed a data entry manual that provided explicit instructions for data entry clerks.

Once the project team installed the tool and completed the training, the data entry effort began. The interface allowed the data entry clerks to enter the attributes for overall intersection and individual leg features using existing satellite and aerial images, including Google Street View™ and Microsoft Bing® Bird's Eye, as well as web map service imagery from a 2011 flyover provided by the University of New Hampshire. The NHDOT GIS database was connected to the user interface and the imagery sources. When the users clicked on the intersection on the GIS map that they wanted to populate, the data entry form for that location automatically appeared with the user interface pre-populated. The user then keyed in the remaining items. The project team developed the interface to have the pre-populated items "grayed" out so they could not be edited by the data entry clerk. These pre-populated data elements were primarily moved to the bottom of the form so as not to confuse or slow down the data entry process. Only the data elements that were being collected could be changed. There were drop-down menus and built in error checks that prevented the user from entering erroneous data. Figure 2 shows a data entry clerk using the user interface. Appendix A includes a description of these error checks.

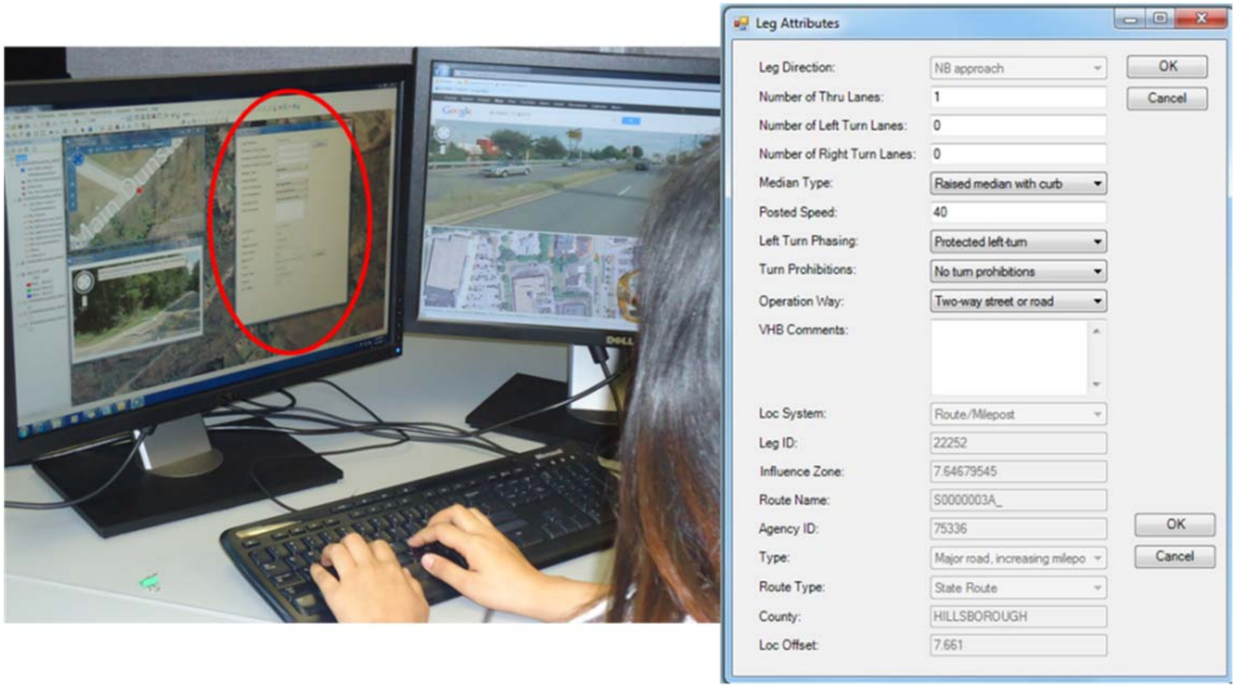


Figure 2. Image of the data collection through the GIS-based intersection inventory builder.

The GIS data were stored in an ArcSDE® geodatabase. This format of geodatabase allowed for multi-user editing and multiple versions. All users had their own version of the database, which helped with the QA/QC process described below in Step 9.

Step 8: Provide Sample Dataset to NHDOT

In order to ensure that there were no issues with the data, the project team provided NHDOT with a sample of the dataset to test the process of incorporating it into its system. . Once NHDOT approved the sample, the project team completed the data collection. Had there been any issues, the project team could have rectified them early on in the data collection process rather than having to go back and fix any issues after all the data had been collected.

Step 9: Conduct Quality Assurance/Quality Control (QA/QC) Reviews

All data entry clerks posted their individual database versions to a "Quality" version of the database once a week. An independent reviewer checked a sample of intersections from each data entry clerk and noted any inconsistencies. The independent reviewer then reported the errors back to each data entry clerk, who was then responsible for fixing those errors and for reviewing their data to ensure similar errors did not exist at other intersections. Once each dataset was corrected, it was then posted to a "Master" database.

Step 10: Field Verification

The project team conducted a field verification of the data elements to compare the differences between data collected in the field and data collected remotely in the office. The team collected data for 200 intersections which included a mixture of urban and rural intersections, 3-leg and 4-leg intersections, and signalized and unsignalized intersections. The field survey crew used the same data entry interface that the office data entry clerks used loaded on a portable tablet, and started with a blank database so as not to be influenced by what was previously collected in the office for the same location. They were also given the same instructions and training as the in-office data entry clerks. Upon completion, the project team analyzed and compared the field data to the data collected in-office. These results are discussed in the New Hampshire *Results* section below.

Step 11: Develop the Traffic Volume Database

NHDOT currently conducts traffic counts on Federal-aid highways for the HPMS every three years (1/3 of their system per year). At the end of every year, NHDOT sends the counts to the Planning Department to be incorporated into the GIS. NHDOT has a GIS snapshot of each years' counts, but does not have one electronic database of historic traffic counts.

As part of this effort, the project team developed an intersection traffic volume database for NHDOT. This electronic inventory of historic traffic count data is stored in a Microsoft Access database format that contains two tables of traffic volume data for the State/State and State/local intersections—one table for Annual Average Daily Traffic (AADT) and another table for turning movement counts (TMCs). The following sections describe the data contained in each table and the methodology behind the table development.

Intersection Annual Average Daily Traffic (AADT)

The project team obtained AADTs from NHDOT for years 2006 through 2010. NHDOT has approximately 5,800 counter stations collecting AADT throughout the State. Each year the Planning Department assigns the counter stations (and its data) to the surrounding roads. The project team used NHDOT's 2011 Asset Roads layer to associate the corresponding road data (and thus counter station ID) to each State/State and State/local intersection leg. Not every road in the State has an assigned counter station, so therefore not every intersection leg had a counter ID assigned to it.

The project team used Microsoft Access to link the counter station AADT data to the intersection legs by way of the associated counter ID. For the legs that did not have a counter ID, the project team assigned an AADT value based on the functional class and county. This is the same methodology the project team used during the development of the intersection inventory and is based on guidance from NHDOT.

Instead of having AADT volumes for each leg of an intersection, the project team consolidated the data into major and minor volumes for each intersection. The team used the major/minor designations assigned to the intersection legs during the development of the intersection inventory. For the intersections that had different volume data for the major (or minor) leg pairs, the project team used the following criteria:

1. If one of the legs had an assigned counter ID and the other leg did not, the data from the leg with the counter ID was kept.
2. If both legs had an assigned (but different) counter ID, the data from the leg with the closest (in distance) counter station was kept. The project team calculated the distance to the counter stations in ArcGIS® using the counter station shapefile provided by NHDOT.

Four percent, or 367 intersections, did not have both major and minor AADT volumes. Approximately 70 percent of these were the nodes the project team identified during the intersection data collection as having errors (e.g., not actual intersections, intersections with missing legs, etc.). The project team left these intersections in the database, but provided them to NHDOT in a separate list.

The database table with the intersection AADT data includes roadway identification data elements (e.g., road name, city, functional class, etc.) in addition to the AADT volumes. Table 3 lists each data element and its definition.

Table 3. Data elements included in the intersection AADT table.

Field Name	Description
AGENCY_ID	Unique intersection ID
MAJOR_MINOR	Indicates if roadway is the major or minor road for the intersection
SRI	Statewide route identifier
ROAD_NAME	Roadway name
CITY	City or town name
COUNTY	County name
FUNCT_CLASS	Functional classification of roadway
LEGIS_CLASS	Legislative classification of roadway
LC_LEGEND	Legislative classification legend
COUNTER_ID	Identification number of the traffic volume counter associated with that roadway
AADT	AADT based on functional classification and county (if no counter assigned to road)
AADT_2010	2010 AADT
AADT_2009	2009 AADT
AADT_2008	2008 AADT
AADT_2007	2007 AADT
AADT_2006	2006 AADT

Intersection Turning Movement Counts (TMC)

The project team obtained TMC data from NHDOT and the State's nine RPCs. The RPCs involved in this effort included:

1. North Country Council.
2. Lakes Region Planning Commission.
3. Upper Valley Lake Sunapee Regional Planning Commission.
4. Southwest Region Planning Commission.
5. Central New Hampshire Regional Planning Commission.
6. Southern New Hampshire Planning Commission.
7. Nashua Regional Planning Commission.
8. Rockingham Planning Commission.
9. Strafford Regional Planning Commission.

The project team identified a primary contact person for each of the organizations. This person was contacted through email and given a brief overview of the project and the data request, which was for intersection counts that were not already in the State system, along with a brief overview of the data collection procedures.

Since many of the counts conducted by the RPCs are submitted to the State, three organizations did not have additional data to provide. These organizations were the North Country Council, the Lakes Region Planning Commission, and the Upper Valley Lake Sunapee Regional Planning Commission. The six remaining RPCs were able to provide data. The TMC data came in various formats (e.g., PETRAPro Software files, Microsoft Excel, PDFs, etc.,), which the project team exported or manually entered into Microsoft Excel as needed.

Once the project team imported all the traffic count data into Excel, the next step was to identify the appropriate intersection and leg IDs. The project team used the available information provided with the TMC data (e.g., road names, city, county, etc.) and the roadway data associated with each intersection and leg from the intersection inventory. If the city name or county name was included in the TMC file, the search was narrowed down to that specific city or county. If not, the project team searched in the intersection list directly for the road name or route number from the TMC file. The intersection ID was considered a match when all legs in the TMC file matched the data in the legs file. If the TMC file did not provide enough identifying information, or the information did not match any of the associated roadway data at the intersections (e.g., it was a count at a local/local intersection), the project team considered it a non-match and did not include it in the database. The project team matched 242 TMC files to 197 intersections. There were approximately 115 files that the project team considered a non-match.

With the intersection ID assigned to the TMC, the project team next identified the leg IDs. In a similar manner as before, the project team used the road information provided in the TMC file to match the leg IDs to the appropriate leg. Aware of the importance to match the correct leg in the TMC file to the correct leg ID, the team used the GIS data files to double check the leg ID. The project team also used Google Maps™ to visually check the intersections and legs.

Upon completion of assigning intersection and leg IDs to the TMC files, a member of the project team performed a QA/QC check on the data. The reviewer assessed a sample of intersections and corrected any errors.

This TMC table contains a row for each State/State and State/local intersection, along with some intersection identification information (e.g., major and minor road name, city, county etc.). Table 4 lists each data element and its definition.

Table 4. Data elements included in the intersection TMC table.

Field Name	Description
AGENCY_ID	Unique intersection ID
SRI_MAJOR	Statewide route identifier for major road
SRI_MINOR	Statewide route identifier for minor road
MAJOR_NAME	Major road name
MINOR_NAME	Minor road name
CITY	City or town name
COUNTY	County name
RPC	Regional Planning Commission
TMC Link1	Hyperlink to spreadsheet of turning movement counts (if available).
TMC Link2	Hyperlink to spreadsheet of turning movement counts (if available).
TMC Link3	Hyperlink to spreadsheet of turning movement counts (if available).
TMC Link4	Hyperlink to spreadsheet of turning movement counts (if available).

The project team linked the TMC data to the Access database via a hyperlink. The intersections that have an associated TMC file show the hyperlinks in those fields. The hyperlink text displays the date of the count. If the user hovers their mouse over the hyperlink, the time of the count will be displayed. This way, the user does not have to open the file to check the time or date of the count. Clicking on the hyperlink will open the TMC data in an Excel file.

Step 12: Integrate the New Dataset into the Current System

For the final step, the project team delivered the database to NHDOT and installed the data collection tool and model on its system. The project team conducted a site visit to NHDOT to deliver the intersection inventory database, GIS models, data forms, and the custom GIS toolbar developed under this project. The project team developed all of the deliverables in ESRI ArcGIS® 10 format. Based on conversations with the NHDOT, the project team anticipated that NHDOT would be operating on ESRI ArcGIS® 10 by the time the project concluded. However, due to internal software conflicts at NHDOT, the department had not yet migrated to ArcGIS® 10 before the project team presented the deliverables. NHDOT was able to load a version of ArcGIS® 10 onto a standalone laptop that was connected to the NHDOT network, allowing the project team to copy over all the project deliverables and demonstrate how the models, data forms, and toolbars worked.

The final deliverables for the project consisted of an ESRI ArcGIS® 10 file geodatabase containing the entire updated intersection inventory for State/State and State/local intersections. In addition, the project team delivered a local/local intersection layer populated with the intersection attributes derived from the GIS models. The project team delivered the GIS models in an ArcGIS® 10 toolbox containing the two models that were developed for the project: (1) New Intersection/Leg Model, and (2) Update (future year) Intersection Model. The project team developed both models using ArcGIS® 10 ModelBuilder™ software. The project team developed the source code for the custom data collection forms and custom toolbar using Visual Studio 2010 (VB.NET) and ArcObjects 10.0 and compiled it all into an ESRI® Add-In with an Extensible Markup Language (XML) configuration file.

The project team loaded the final deliverables onto the NHDOT laptop running ArcGIS® 10. The team demonstrated how to setup the configurations files, install the custom toolbar, and execute each of the GIS models to ensure that the deliverables were functioning correctly on a local NHDOT system. Once NHDOT completely migrates to ArcGIS® 10, NHDOT will be able to fully integrate the new data and tools into the NHDOT enterprise GIS and share the information across their network.

As discussed, the project team delivered a sample dataset to NHDOT to import into their system, which was evaluated successfully for use in *SafetyAnalyst*. Because there were no issues with the sample data, it is not anticipated that there will be any significant issues with integrating the completed intersection inventory into NHDOT's GIS.

Results

The development of the data collection tools and model began in January 2012 and took approximately three months to complete. The project team completed the data collection for all 10,300 intersections in five months (March 2012 - July 2012). The project team initially estimated the data collection to take six months to complete, but it only took five months. The team estimated the data collection to take approximately 2,000 person-hours but it only took 1,600 person-hours. At any given time over the data collection period, there were three to five data collection stations that were manned almost full-time. The management and QA/QC time took slightly more hours than initially planned, but was more than offset by the reduction in the data collection time. The initial estimates were based on 10-12 minutes per intersection, but it took only an average of 9 minutes per intersection.

Throughout the data collection process, the number of intersections completed per hour improved for each data entry clerk. At the start of the data collection it took almost 12 minutes per intersection; however, by the end, it took approximately seven minutes per intersection. Error rates also improved through the data collection period. Since this process is repetitive in nature, the more familiar the clerks became with the process and the data elements, the more efficient they became.

As discussed in Step 10, the project team collected data in the field from a sample set of intersections. Collecting data in the field provided an opportunity to compare the differences between in-office (remote) data collection and field data collection. The project team analyzed the two datasets with some surprising results. In many cases, especially for geometric elements, the in-office data were more accurate. This was because the bird's eye view of aerial imagery allowed the data collectors to see the geometry better than when on the ground. An example of this is T- versus Y-intersections. In other cases, the field data proved more accurate than the in-office data, especially for the signal timing elements since the technicians in the field could observe the timing, whereas in the office they had to rely on a frozen snapshot. Overall, the field collection took almost twice as long per intersection as the in-office data collection.

The entire effort, including the development of the intersection inventory and the traffic dataset, cost approximately $210,000, which FHWA funded through the MIRE MIS Lead Agency Program. Table 5 lists the hours spent on each task, rounded to the nearest five hours, and the total cost.

Table 5. Breakdown of hours by task and total cost for New Hampshire intersection inventory.

Activity	Hours
Coordination with NHDOT and development of a Work Plan	455
Development of model that pre-populated the inventory	75
Development of the data collection tool/interface to collect the remaining data	175
Develop node layer for the 24,000 local/local intersections	30
Hiring and training of data collection clerks including development of collection manual	135
Collection of intersection data:	
In-office collection for 10,300 intersections	1,600
In-field data collection for 200 intersections	60
Management and QA/QC	360
Development and delivery of a dataset of existing intersection traffic volumes	375
Providing the dataset, model, and tool to NHDOT and setting-up and training	25
Total Cost	***$210,000***

**Note:* Total cost is in 2012 dollars and may vary by agency.

Challenges

The largest obstacle during data collection involved determining posted speed limits, as it required the most time of any data element. NHDOT does not have a speed limit database, so the project team needed to collect posted speed limits for each approach by visually identifying speed limit signs. However, the signs were often not right at the approach and the data entry clerks had to "drive" down the street using Google Street View™ to find the speed limit sign. The data entry clerks were challenged with developing an efficient method to collect this information. The method adopted by the majority of the data collectors was to print out a map of the corridor and then "drive" the corridors using Google Street View™, noting on the map the location of the speed limit signs and the posted speed limit. Then, when entering the data on the approach leg, they could quickly reference the map.

Lessons Learned

Many factors contributed to the success of this effort, such as:

1. **Development of the Work Plan:** The work plan provided a clear vision and approach for conducting the data collection. This helped to lay out clear expectations on the part of NHDOT and the project team.

2. **MIRE flexibility:** The primary goal of this effort was to test the feasibility of collecting MIRE data elements. Both NHDOT and WSDOT requested an intersection dataset to import and use in *SafetyAnalyst*. The project team developed data collection tools to create a database to be able to meet that goal. While the data elements selected by the States were based on MIRE, the data collected required deviations from the MIRE data dictionary in order to tailor them for *SafetyAnalyst*.

3. **Constant contact/feedback between the contractor and the State DOT:** Throughout the entire process, NHDOT was available to answer questions and to provide clarification and feedback. This constant communication was key to developing a dataset that best met their needs.

4. **Development of a "Frequently Asked Questions" document:** Since there were multiple data entry clerks simultaneously entering data, there were several similar questions that came up in the beginning of the data collection effort. The project team developed a Frequently Asked Questions (FAQ) document. Each time a data entry clerk asked a question, the project team added that question and its response to the FAQ document. The data entry clerks were instructed to review the document every morning. This helped to provide a level of consistency among the various staff members.

5. **Data collection flexibility:** Each data entry clerk had the flexibility to collect the data in the manner that was most efficient for them. Some collected all of the speed limits first within a corridor; some did all of the intersections, then all of the legs. By allowing this flexibility, each data entry clerk was able to maximize his or her efficiency.

6. **Use of the sample dataset:** The project team provided NHDOT a sample dataset to ensure there were no problems with the data. Although none were found, if there had been issues, they could have been resolved before completing the data collection rather than having to go back and correct the data—thus saving valuable time, budget, and resources.

7. **Use of GIS tools:** The tool was completely GIS-based using ESRI® products and did not require any proprietary software. This allowed the project team to install it on NHDOT's system, allowing NHDOT to continue the data collection effort in the future.

8. **Use of existing data:** The project team was able to derive many of the basic intersection inventory elements from existing data sources. Out of the 31 elements for the overall intersection, the project team only needed to collect four elements; the remaining 27 either already existed or were derived from existing sources. Out of the 23 elements for each intersection leg, the project team only needed to collect eight; the remaining 27 either already existed or were derived from existing sources.

9. **Temporality of the collected data:** In order to better ascertain how current the roadway inventory data are, the date of visual imagery from which the data are extracted should be recorded. This provides information regarding the currency of the data. This information could be recorded as metadata.

WASHINGTON STATE

Similar to the effort conducted with NHDOT, the starting point for WSDOT was the MIRE listing. As part of the application process, WSDOT reviewed the MIRE elements and provided a list of the elements they would like to have collected. WSDOT organized their selected elements into three priority categories—high, medium, and low. Taking into account the funding available to complete the work, WSDOT requested the project team collect the high and medium priority elements. However, the project team also collected one low priority element, circular intersection data, at the request of WSDOT. Table 6 provides the list of requested elements, which include identification, location, operations, geometric, and traffic data.

Approximately 76,000 centerline miles of roadway exist in the State of Washington. The State owns and maintains only about 7,000 centerline miles of this roadway, and WSDOT collects and maintains roadway data only on the State-owned roadways. Given the vast road network and the limited funding available for this effort, the project team and WSDOT acknowledged that it might not be feasible to develop an inventory and collect the data elements for all public roadway intersections in the State. Since WSDOT has a base GIS layer of State/State intersections (approximately 320) and State/local intersections (approximately 17,200), the State prioritized these intersections over other intersection types (such as, local/local and local/ramps or interchanges) to maximize the benefit from this work. The State also requested that all circular intersections be included in the data collection effort. In addition, the project team was responsible for assigning existing traffic volumes to all intersection types within the dataset. Ultimately, the project team collected data for approximately 15,820 spatially distinct State/State and State/local intersections in the intersections geodatabase.

Table 6. Intersection inventory elements requested by WSDOT.

Intersection Elements	Intersection Leg Elements
Unique Junction Identifier	Unique Approach Identifier
County Name	Major Commercial Driveway Count
Rural/Urban Designation	Minor Commercial Driveway Count
AADT Annual Escalation Percentage	Major Residential Driveway Count
Type of Intersection/Junction	Minor Residential Driveway Count
Intersection/Junction Geometry	Major Industrial/Institutional Driveway Count
Intersecting Angle	Minor Industrial/Institutional Driveway Count
Intersection/Junction Offset Flag	Other Driveway Count
Intersection/Junction Offset Distance	Number of Approach Through Lanes
Intersection/Junction Traffic Control	Number of Exclusive Left Turn Lanes
Signalization Presence/Type	Number of Exclusive Right Turn Lanes
Route Number, Route/Street Name	Speed Limit
Circular Intersection – Circulatory Lane Width	Approach AADT
Circular Intersection – Inscribed Diameter	Approach AADT Year
Circular Intersection – Entry Width	Approach Directional Flow
Circular Intersection – Presence/Type of Exclusive Right Turn Lane	Approach Traffic Control
Circular Intersection – Entry Radius	Approach Left Turn Protection
Circular Intersection – Exit Width	Left/Right Turn Prohibitions
Circular Intersection – Number of Exit Lanes	Right Turn-On-Red Prohibitions
Circular Intersection – Exit Radius	Left Turn Counts
Circular Intersection – Crosswalk Location	Year of Left Turn Counts
Circular Intersection – Island Width	Right Turn Counts
	Year of Right Turn Counts
	Right Turn Channelization

Methodology

The project team followed the following general steps to develop the WSDOT intersection inventory:

1. Determine what data are already collected and what remaining data need to be collected.
2. Determine how the data are currently collected, the available data sources, and how to collect the new data.

3. Develop a detailed work plan.
4. Develop the data collection tool and interface.
5. Collect the data – manual survey.
6. Develop automated import of existing data.
7. Conduct quality assurance/quality control (QA/QC) reviews.
8. Provide a sample dataset to WSDOT.

Step 1: Determine Existing Data and Remaining Data Needs

The project team first determined which of the WSDOT-requested elements were already being collected. Over a series of onsite meetings, the project team worked with the WSDOT staff and reviewed their data collection practices and datasets. The project team identified several existing data sources that provided coverage for the data collection needs of this project. The sources, and the data contained in them, included:

1. WSDOT Roadway Datamart – A collection of geospatially-referenced datasets broken into multiple tables. The project team made use of the following tables:
    a. Intersections.
    b. Lanes.
    c. LegalSpeedLimits.
    d. UrbanRural.
2. Signs, Signals, and Intersections Geodatabase:
    a. Traffic Signs.
    b. Signals_FlashingBeacons.
    c. Signal_Beacons_OpsInfo.
    d. TurnLanes.
3. County Road Administration Board (CRAB) Mobility Database:
    a. Roadlog.
    b. RoadMaster.
4. Functional Class Geodatabase:
    a. FunctionalClassStateRoute.
    b. FunctionalClassNonStateRoute.
5. Traffic Geodatabase (developed for WSDOT by third party vendor):

a. TRAFCWA – A database of projected traffic counts for the State of Washington.

b. Growthrateswa – A database of projected traffic growth rate zones for the State of Washington.

These datasets often contained overlapping information. Due to its design, the collection database represents all sources of data. The final data transformation step aggregated overlapping data points (for a given intersection or leg element and data field) according to WSDOT data source preferences.

Step 2: Determine How Data Are/Will be Collected

Conducted concurrently with Step 1, the project team worked with WSDOT to determine how it currently collects and stores the data. The State roadway inventory system is based on an LRS that feeds into WSDOT's Datamart, which can link to other datasets such as traffic counts and crash data. The data contained in the State Highway Log are collected and updated using contract plans, field reviews, and information provided by numerous WSDOT regional and headquarters offices, as well as other county and city sources. Video of the roadway is collected via a digital imagery van. Washington uses GIS for mapping their data. Included in WSDOT's Datamart is a geodatabase of State/State intersections. When two State routes meet at an intersection, they are represented by two spatially-coincident records in the intersections geodatabase.

Traffic data are also a critical piece of information for safety analysis, particularly for use of the *SafetyAnalyst* software. WSDOT collects and stores data on the State-maintained highway network. There are a number of local organizations responsible for collecting and storing traffic data on local roads. The data collection processes, data sampling, data interpretation, data storage, and extent of available historical information vary between WSDOT and the various local agencies. There is no single database and data format to easily access this traffic data and not all data are available for a given current year (a current year estimate is essential for safety analysis). The process to gather, interpret using a consistent set of tools, and compile the data into a single database with a common geospatially-referenced data format for use under this effort would have taken considerable effort. As part of this project, the project team sought third-party vendors to provide this information and supply it in a readily usable format with the intent to reduce the data collection, interpretation, and formatting costs.

The project team selected a vendor who had 32,856 traffic counts in Washington State. The traffic counts the vendor provided are those published by the various city, State, and Federal organizations. The vendor developed a methodology using the raw published counts to derive the best feasible current year traffic volume estimates in terms of Annual Average Daily Traffic (AADT). A total of 18,315 such estimates are available in the database; all data are geospatially referenced. The project team determined this was a cost effective way to obtain the necessary traffic data for this project.

Based on the information obtained from WSDOT, the third party vendor, and the data currently available, the project team established two primary methods of data collection: manual collection and automated import. Table 7 presents the data items that were collected manually, imported automatically, or both. For the manual collection phase, the project team developed a tool that presented aerial and ground photography and any associated GIS layers to the user, as well as the Google Maps™ and Microsoft Bing® map of the intersection. For the data import phase, the project team created source-specific importers that mapped geospatially referenced data to the intersection and leg inventory according to the relevant geometries.

Table 7. Elements and primary method of data collection for WSDOT intersection inventory elements.

Intersection Elements	Intersection Leg Elements
Unique Junction Identifier (Imported)	Unique Approach Identifier (Imported)
	Number of Approach Through Lanes (Manual/Imported)
County Name (Imported)	Number of Exclusive Left Turn Lanes (Manual)
	Number of Exclusive Right Turn Lanes (Manual)
Rural/Urban Designation (Manual/Imported)	Speed Limit (Imported)
	Approach AADT (Imported)
AADT Annual Escalation Percentage (Imported)	Approach AADT Year (Imported)
	Approach Directional Flow (Manual)
Type of Intersection/Junction (Manual)	Approach Traffic Control (Manual/Imported)
	Approach Left Turn Protection (Manual/Imported)
Intersection/Junction Geometry (Manual/Imported)	Left/Right Turn Prohibitions (Manual)
	Right Turn-On-Red Prohibitions (Manual)
Intersecting Angle (Imported)	Left Turn Counts (Imported)
Intersection/Junction Offset Flag (Imported)	Year of Left Turn Counts (Imported)
	Right Turn Counts (Imported)
Intersection/Junction Offset Distance (Imported)	Year of Right Turn Counts (Imported)
	Right Turn Channelization (Manual)
Intersection/Junction Traffic Control (Manual/Imported)	Circular Intersection – Entry Width (Manual)
Signalization Presence/Type (Imported)	Circular Intersection – Presence/Type of Exclusive Right Turn Lane (Manual)
Route Number, Route/Street Name (Imported)	Circular Intersection – Entry Radius – (Manual)
	Circular Intersection – Exit Width – (Manual)
Circular Intersection – Circulatory Lane Width (Manual)	Circular Intersection – Number of Exit Lanes (Manual)
	Circular Intersection – Exit Radius (Manual)
Circular Intersection – Inscribed Diameter (Manual)	Circular Intersection – Crosswalk Location (Manual)
	Circular Intersection – Island Width (Manual)

Step 3: Develop Detailed Work Plan

The project team developed a detailed work plan. The work plan provided an overview of the proposed effort, including timeframe and cost, and included a description of WSDOT's existing data system, including sources of available data.

Following the development of the work plan, the project team developed a detailed data dictionary. The data dictionary included the attributes and important considerations for each element. Since WSDOT intends to use the dataset for *SafetyAnalyst*, the project team created a model that mapped the MIRE elements to the corresponding *SafetyAnalyst* fields (where applicable). Higher order discrepancies between the two models (MIRE and *SafetyAnalyst*) ultimately led the project team to abandon this method. Instead, the team identified each element, defined the element using both the MIRE and *SafetyAnalyst* definitions, and assigned allowable values. For the data elements with numeric fields, the project team identified specific values. The creation of the data dictionary also involved adding proposed data sources and technical field information (, data type and size).

Step 4: Develop Data Collection Tool and Interface

The project team designed a data collection tool called the MIRE Intersection Data Survey (MIDS) tool, which provides a platform for integrated data sources used to conduct manual data collection (i.e., GIS maps, third-party databases, and State databases). The MIDS tool builds on concepts that members of the project team used in a previous data collection project (the FHWA Indian Roads Functional Classification). The goal of the tool was to present multiple and complimentary data sources to the users so they could accurately determine the required input fields.

The project team developed the MIDS tool in the C# programming language using the Visual Studio® 2010 Integrated Development Environment (IDE) and utilizes the .NET 4.0 Framework. The tool works on any Microsoft operating system later than Windows® XP Service Pack 3 (i.e., Vista®, Windows® 7, and Windows® 8). The project team used Microsoft SQL Server® 2008 R2 database for the tool, which is forwardly compatible with Microsoft SQL Server® 2012.

The MIDS tool provides many different data sources used for data entry, data viewing, tracking, and visual imagery, which are accessed via specially designed windows:

- Explorer window: displays interface for navigating between intersections.
- Google Earth™ window: displays aerial imagery from Google Earth™ with associated layers and options. Allows import/creation of keyhole markup language (KML) files. Includes drawing tools for collecting measurement data fields.
- Microsoft Bing® Map window: displays Microsoft Bing® aerial and Bird's Eye Imagery.

- Google Street View™ window: displays Google Maps™ and Google Street View™ imagery.
- SR View window: displays WSDOT videolog imagery.
- Output window: provides feedback to the users.
- Survey window: displays the data entry interface.
- Changes window: provides summary of manual data entry.
- Efficiency window: tracks user's data entry progress.

Figure 3 is an example of the various data windows that are part of the MIDS tool. Notice that some windows are fully visible and some are shown as tabs. Each window can be moved based on the user's preferences. Tabs allow for larger windows and fast transition between the different windows.

The Explorer window shows the intersections grouped by county and route. At the route level, intersections are ordered by milepost to provide a logical survey progression. Progress bars provide visual representation of survey progress. It is possible to search for intersections by name within a route. If a letter is typed on the keyboard, the next intersection in the list starting with that letter will be highlighted. This window is also connects to the imagery and survey windows. When the user clicks on an intersection in the explorer list, Google Earth™, Google Street View™, and Microsoft Bing® Map automatically center on that location while keeping the zoom level constant. The Survey window automatically shows only the data for that intersection.

The Google Earth™ window provides aerial imagery of the intersection, along with a set of GIS tools for annotating the intersection. It is possible to load existing files and create new KML files. Linear and circular measurement tools are provided within the interface so that measured fields (e.g., entry width, circulatory width, and inscribed diameter, etc.), can be surveyed and saved for later checks and audits. These options are organized in a collapsible control panel. Intersection approach angles can also be determined using the compass which is automatically centered on the active intersection. Figure 4 is a screenshot of the Google Earth™ window.

Figure 3. Screenshot of window configuration.

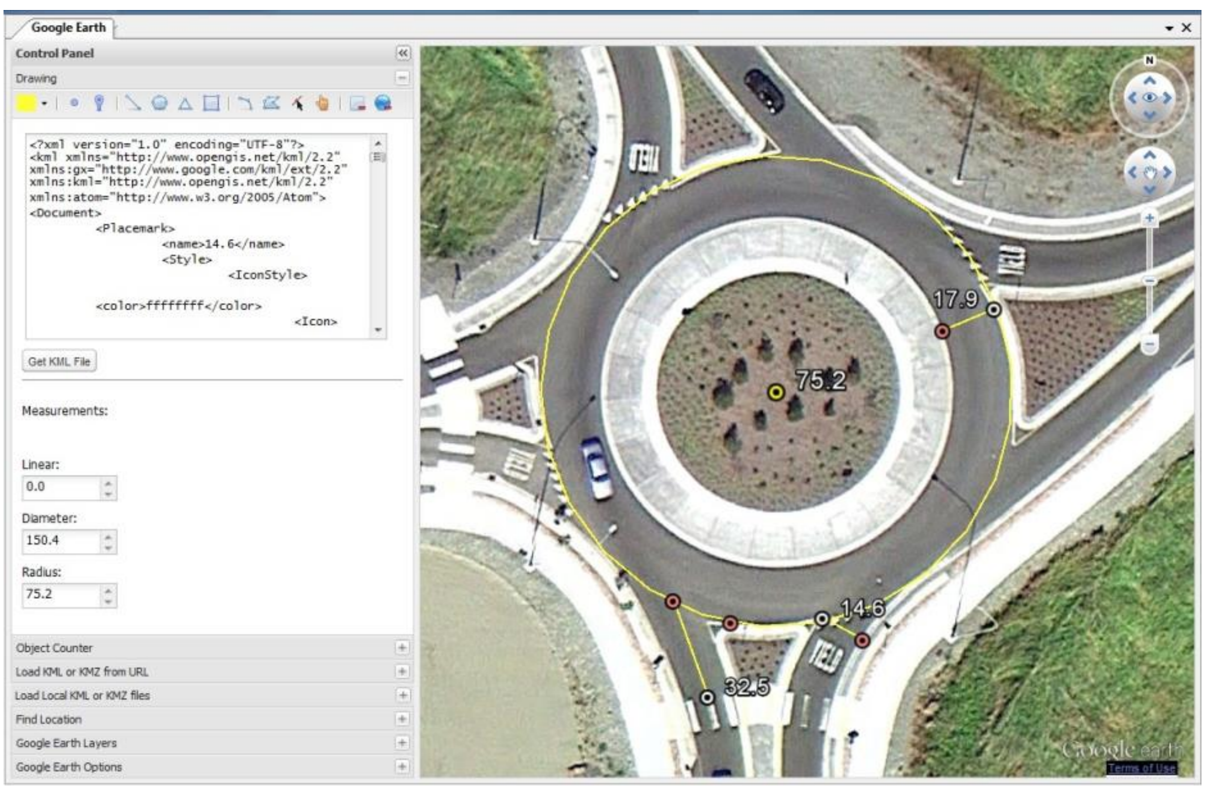


Figure 4. Screenshot of Google Earth™ window with expanded control panel.

The Bing® Map window provides information similar to the Google Earth™ window, but with a different set of aerial photographs, dates, and resolutions. The Bing® Map window does not contain the KML editing tools. The purpose of this window is to supplement the aerial imagery provided by the Google Earth™ window.

The Google Street View™ window provides ground-level imagery. Each intersection can be viewed from multiple directions so the user can identify signs and traffic signals.

SR View is WSDOT's videolog database. It acts as a supplement to Google Street View™ as it also provides ground-level imagery. While Google data are available for most of the United States, SR View is only available for routes maintained by WSDOT. It is an example of custom integration of agency specific tools. The project team developed MIDS to allow the addition of custom tools with minimal additional coding.

Having multiple sources for both aerial and ground imagery is helpful in locations where vegetation and/or traffic block the data elements. Figure 5 shows an example of the Bing® Maps (top left), SR View window (bottom left), and Google Street View™ (right) imagery arranged as separate, floating windows.

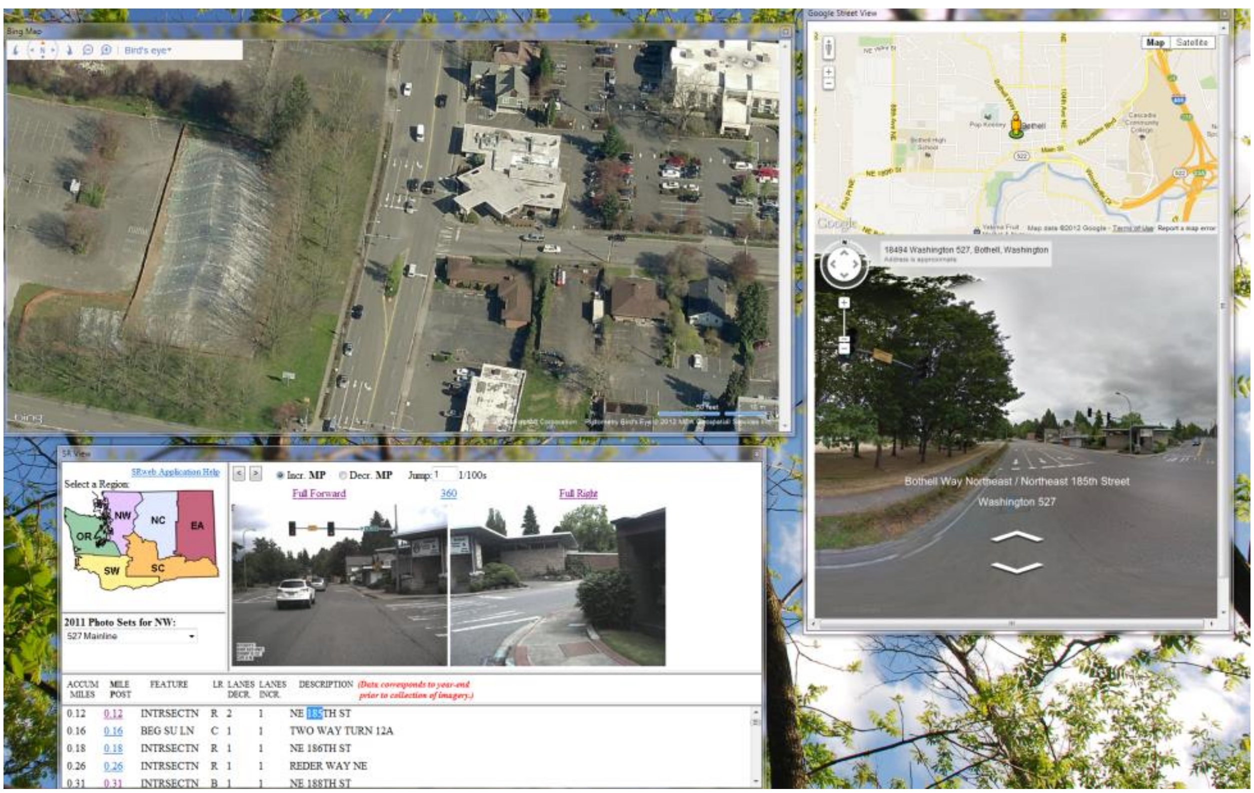
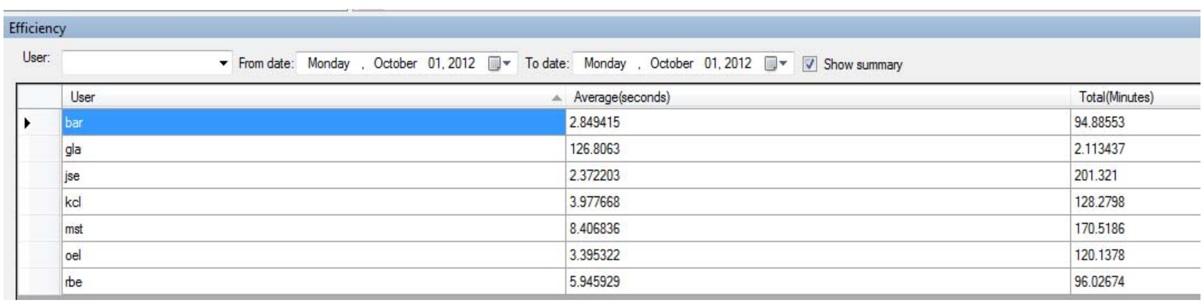


Figure 5. Screenshot of imagery windows.

The Output window provides feedback to the user including error messages, user hints, and other information. The user can choose to dock the Output window behind other windows to provide additional space for the other survey information.

The Survey window is the main interface data entry clerks use to input data. The Survey window is configurable by changing the FIELD_MAP table in the tool's primary database. Surveyors enter the numerical data by typing and text data are chosen from dropdown menus. The Survey window is connected to the Changes and Efficiency windows so that each change to the database is logged and processed.

The Changes window is a summary of all the data entered for each intersection. Each data entry clerk had a unique username to allow the project team to track their data entry. This also allows the tool to calculate the efficiency of each surveyor. Figure 6 is a screenshot of the Efficiency window in the MIDS tool. Graphing efficiency on a daily basis, as shown in Figure 7, allows the project team to track progress and set data collection goals. Another benefit of usernames is that each surveyor can personalize the window locations on their workstation based on the number of monitors being used and personal preference. Upon each login to that computer, the tool windows open in the same place as when the program was last exited.


Efficiency
User: From date: Monday , October 01, 2012 To date: Monday , October 01, 2012 Show summary

User	Average(seconds)	Total(Minutes)
bar	2.849415	94.88553
gla	126.8063	2.113437
jse	2.372203	201.321
kcl	3.977668	128.2798
mst	8.406836	170.5186
oel	3.395322	120.1378
rbe	5.945929	96.02674

Figure 6. Tool-generated efficiency.

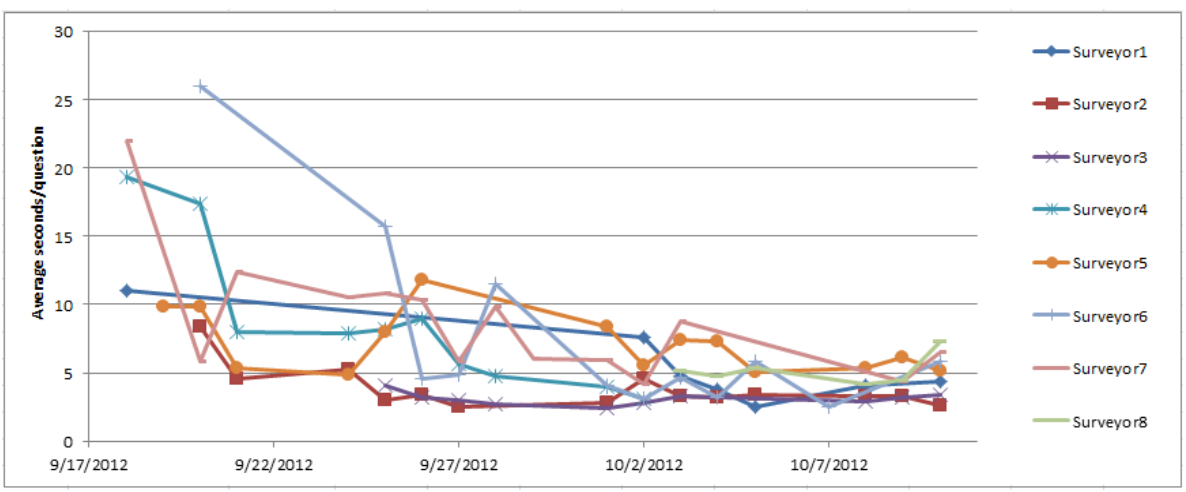


Figure 7. Graphing surveyor efficiency over time.

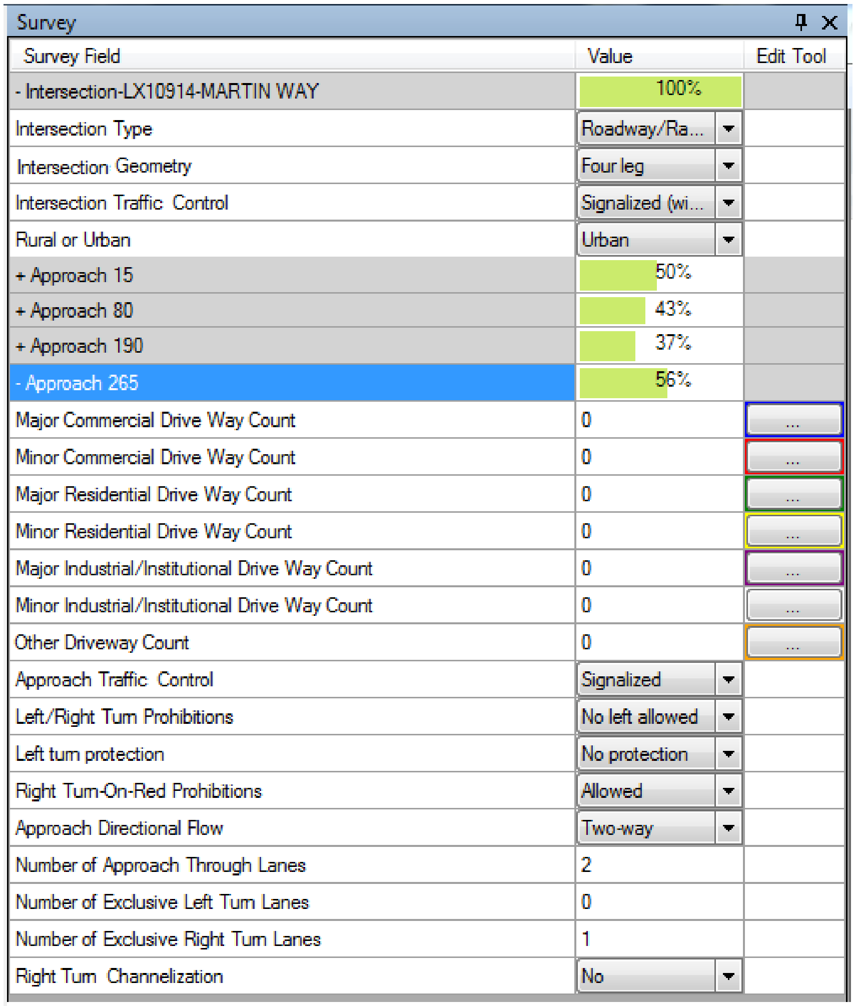
Step 5: Collect Data – Manual Survey

Before the data collection began, the project team selected a team of data entry clerks and set up the appropriate number of workstations to accommodate them. The majority of the data entry clerks worked in a single room so that they could exchange questions and data collection tips very quickly. The project team held a group training session to familiarize the clerks with the tool. The team also provided individual training sessions to each data entry clerk to clarify the process. This training included working through multiple examples and pointing out subtle clues in the aerial imagery, such as lane alignment and shadow recognition, to prepare them for solo data collection. As part of the training, the team developed a survey manual that provided detailed descriptions of data fields and instructions.

At the start of the data collection effort, the project team assigned each data entry clerk a county. Each clerk was responsible for completing all intersections in their county before moving on to another county. The MIDS tool allowed the users to enter data into the database without manually saving any changes. This reduced the required motions of the mouse and number of keystrokes, and safe-guarded data in the case of unexpected shutdown. In addition, a user could view recent changes made by other users without disrupting their data entry or restarting the program. The design of the tool makes accidental survey overlap nearly impossible.

After logging in, the data entry clerks could quickly find where to start collecting data by navigating through the tree in the Explorer window. The progress boxes next to each level in the tree made it easy to see which intersections were complete. The built-in automation of zooming to the correct location when selecting intersections prevents users from having to search for the correct location and saves valuable time.

The Survey window contains the data fields that are arranged vertically and grouped by intersection and intersection leg. This method of organization helped the user to first recognize the intersection as a whole before narrowing their attention to the specific details of each leg. This feature also allowed the data entry clerks to become familiar with common intersection geometries and traffic patterns which increased data collection efficiency. Text field drop-down menus prevented the user from entering erroneous data. To further reduce the amount of data entry, the project team pre-populated some fields with values from the WSDOT database such as intersection geometry and intersection traffic control. Figure 8 shows the data layout within the Survey window. Note that surveyors can minimize or expand the set of data for each approach with the ease of a double click.



Survey

Survey Field	Value	Edit Tool
- Intersection-LX10914-MARTIN WAY	100%	
Intersection Type	Roadway/Ra...	
Intersection Geometry	Four leg	
Intersection Traffic Control	Signalized (wi...	
Rural or Urban	Urban	
+ Approach 15	50%	
+ Approach 80	43%	
+ Approach 190	37%	
- Approach 265	56%	
Major Commercial Drive Way Count	0	...
Minor Commercial Drive Way Count	0	...
Major Residential Drive Way Count	0	...
Minor Residential Drive Way Count	0	...
Major Industrial/Institutional Drive Way Count	0	...
Minor Industrial/Institutional Drive Way Count	0	...
Other Driveway Count	0	...
Approach Traffic Control	Signalized	
Left/Right Turn Prohibitions	No left allowed	
Left turn protection	No protection	
Right Turn-On-Red Prohibitions	Allowed	
Approach Directional Flow	Two-way	
Number of Approach Through Lanes	2	
Number of Exclusive Left Turn Lanes	0	
Number of Exclusive Right Turn Lanes	1	
Right Turn Channelization	No	

Figure 8. Screenshot of data in survey window.

The SR View, Google Earth™, Bing® satellite view, Bing® Bird's Eye View, and Google Street View™ windows give the user a lot of view options for collecting data. The primary window used for finding field information was usually Google Earth™, but it depended on the image quality and image date. An example of image quality difference is shown in Figure 9. Some intersections that appear clearly on the Bing® map can appear as blurry construction sites on Google Earth™ (or vice versa). The different view options are also important for determining fields that are dependent on non-durable paint marks and for those that could be blocked by vegetation.

Google Earth™ image (left) and Microsoft Bing® (right).

Figure 9. Imagery differences.

The surveyors used Google Street View™ heavily for data fields that are defined by signs, such as turn prohibitions. Figure 10 is an example of ideal imagery. This single view allowed the user to collect Traffic Control, Left/Right Turn Prohibitions, and Left Turn Protection. Familiarity with common sign appearance and locations allowed for more accurate data collection, even with unclear imagery. Surveyors used SR View less frequently, typically only when Google Street View™ did not offer acceptable visibility. SR View is the only imagery window that does not automatically locate the intersection.

Figure 10. Clear Google Street View™ imagery.

When a data entry clerk encountered a question that could not be answered expediently, they marked the intersection for review. As shown in Figure 11, a red box is drawn next to the intersection name so it can be easily found and reviewed at a later time. Often, a user would survey an entire route and then review any marked in red. A different surveyor reviewed the remaining marked intersections prior to QA/QC.

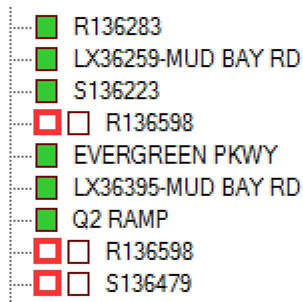


Figure 11. Screenshot of intersections marked in red for survey review.

The intersection dataset from WSDOT contained many intersections that were not included in the survey. These included duplicate intersections, intersections that were combined with others (e.g., offsets), locations where roadways come together without traffic intersecting, and locations where channelized exclusive turn lanes met the roadway. Surveyors flagged these intersections to show they were skipped. Intersections under construction in the imagery were also flagged and skipped. These intersections were included in the QA/QC process to determine if they were correctly skipped or if they needed to be fully surveyed. Approximately 2,680 intersections (14.5 percent) were flagged and skipped.

Some intersections in the dataset were reversible, meaning that traffic directions for each leg could be different depending on time of day. These intersections were given a unique flag to show that the surveyors collected data for one possible traffic configuration for the intersection. Not all intersections with the word "reversible" in their description were truly reversible intersections by the above definition. Some of these include entrances or exits to reversible lanes but are only in use for one direction. These cases were surveyed as normal intersections for the direction in which they were used and did not receive a flag.

The survey administrator was able to manually enter a limited number of comments into the database to record survey decisions on complicated intersections; however, future efforts should incorporate a way to enter and view survey notes through the MIDS tool.

Step 6: Automated Import of Existing Data

The second part of the data collection phase involved the automated import of existing data. For this phase of data collection, the project team created source-specific importers that mapped geospatially-referenced data to the intersection and leg inventory according to the relevant geometries.

The import of the intersection inventory was relatively straightforward. The project team took data directly from the intersection geodatabase and keyed to a geospatially-generated ID. The team generated the ID using the Bing® Maps tile numbering scheme to identify and eliminate coincident records *(8)*.

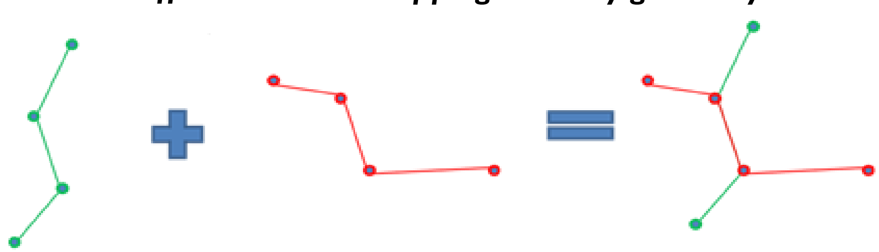
The import of the intersection leg data was more challenging. The project team developed a custom model to extract geometry data from the State and non-State functional class geodatabases and determine intersection associations by lowest-distance parameters. The development of the import model started with linestring matching algorithm, which operated as follows:

1. Partitioned the data into county-sized chunks to reduce the number of pairings that are not possible.
2. Wrapped leg geometries in a convex hull (see examples below) and calculated their area as projected onto an Earth-sized sphere.
3. Wrapped linestrings for the data to be imported in a convex hull and calculated their area as projected onto an Earth-sized sphere.
4. For each county, checked each pair of legs/data linestrings by wrapping a convex hull around both the leg and data linestrings and computing that area.
5. Produced an error metric by subtracting each of the individual areas from two times the combined area and dividing by two times the summed length of the leg and data geometries.

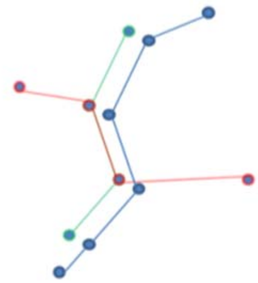
Example of the Linestring Algorithm Process

The following example provides a general description of the linestring algorithm process:

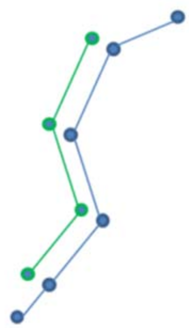
Difficult case: overlapping roadway geometry.



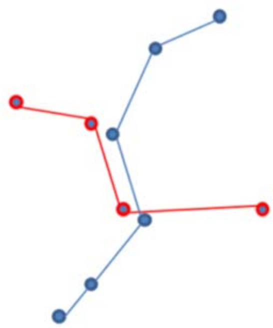
Position of attribute data:



Good Match:

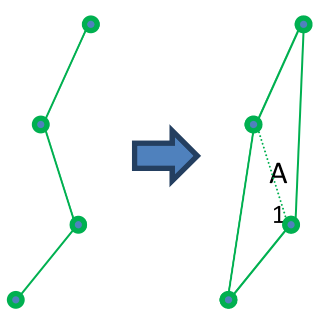


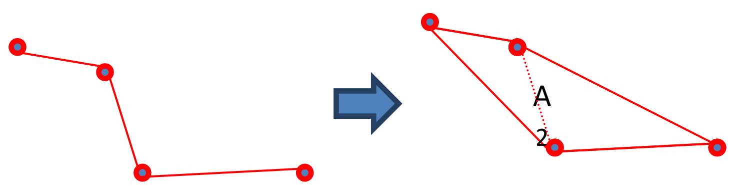
Bad Match:



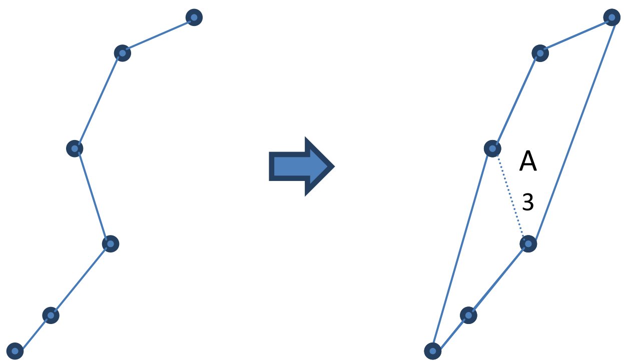
This matching is obvious to human eyes, but needs to be quantifiable for a computer to match it.

For each pairing of inventory and attribute geometries, a simple scalar value that represents how well the data match is needed. Step 1: Wrap a convex hull around the inventory geometry and calculate the area as projected on a great-sphere approximation of the earth. The original inventory is shown as a dotted line inside the hull.

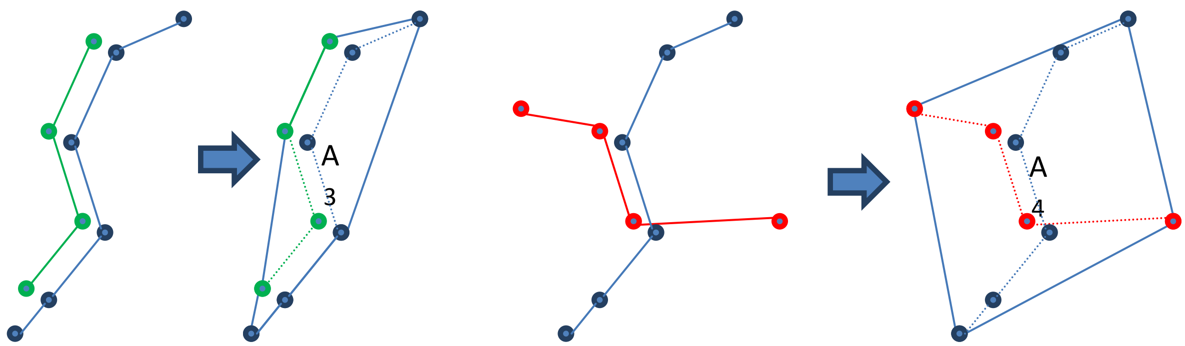




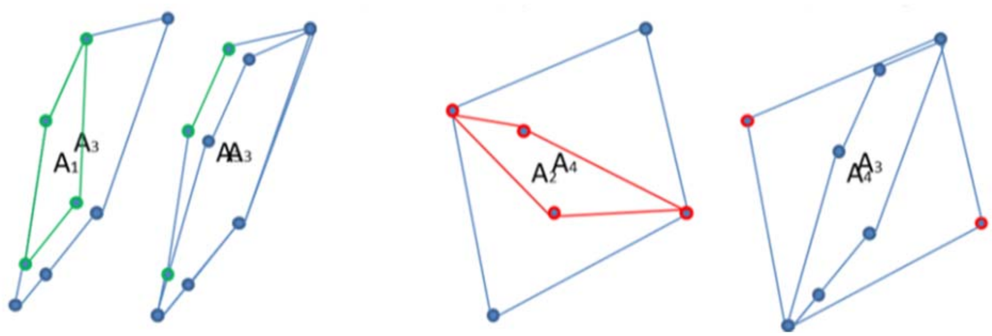
Step 2: Do the same for the attribute geometry.



Step 3: Now wrap a convex hull around the inventory AND attribute geometries.



If the inventory and attribute geometries overlap exactly, the sum of their convex hull areas will be equal to twice the area of the combined convex hull (since the points will lie on top of one another). If they are close, the left-over area will be small (and will simply need to be normalized by the lengths of the shapes).



This error metric closely approximates the distance between the linestrings that served as an excellent matching heuristic for line-line matching problems. Point data were handled in a simpler way by looking at straight line distances (either directly to the checked intersection point or to the closest point on the relevant leg) to determine best matches.

Matching Data from the Import and Manual Collection

Upon completion of the two data collection phases, the next step required matching the manually collected data and the imported data. The matching of intersection inventory datasets was simplified since both datasets (i.e., manual and imported) had the same data elements. The leg inventory featured different elements, and as such the matching of data proved more complicated.

The project team assigned each manual/imported leg pair an error value according to the difference in degrees of their bearing. For pairs of intersections with the same number of legs, matching simply involved choosing the consistent pairing (meaning all legs are matched once and only once) with the lowest total error rate. For pairs of intersections with a disparate number of legs, leg matching proceeded in a similar way, but with the constraint of complete matching relaxed (while still looking for the lowest total error). Import of any leftover legs simply copied whatever data were available and flagged the intersection for QA/QC.

Step 7: Conduct Quality Assurance/Quality Control (QA/QC) Reviews

The QA/QC reviews required that the project team scan the manual survey data for logic errors using a series of SQL queries. (Appendix A includes the list of the SQL queries used during this process.) Any errors found were manually checked and edited. It was important to implement this step multiple times during the survey process because it helped identify reoccurring errors made by specific surveyors. These errors can be corrected early to reduce the amount of required edits later in the survey.

The manual survey data also underwent a quality check to determine the accuracy of the data collection. A random sample of five percent of the intersections was chosen for QA/QC. These intersections were automatically marked with a blue box in the Explorer window for administrative users only. An olive-colored box, for example SR 5 NB in Figure 12, indicated the completion of QC for an intersection, which provided to visible confirmation of the QC survey progress. Figure 12 shows a screenshot of the marked intersections. The designated quality inspector logged into the tool using an administrator user name and reviewed the data for the marked intersections. If an error was found, it was immediately corrected and the change automatically logged by the tool.

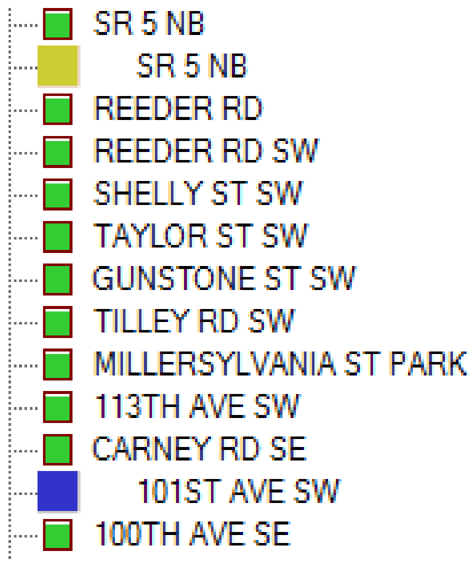


Figure 12. Screenshot of intersections marked for QA/QC.

The project team could use the MIDS data log to identify all of the errors corrected by the quality inspector and calculate the survey accuracy for individual data fields. Table 8 shows the percent of errors found in each manually surveyed field in the QA/QC dataset. It is important to note that the WSDOT QA/QC effort began before some of the logic queries were developed. These queries were very important to improving the accuracy of surveyed data. Some errors caught by the quality inspector may have been corrected by queries and not included in the final accuracy. The survey team is confident that no data element has an actual percent error higher than 10 percent. Appendix A lists the logic queries used for the QA/QC effort.

Table 8. Calculated percent error of sample.

Elements	Percent Error
Intersection Elements:	
Type of Intersection/Junction	2%
Intersection/Junction Geometry	7%
Intersection/Junction Traffic Control	5%
Rural/Urban Designation	2%
Intersection Leg Elements:	
Approach Traffic Control	9%
Approach Left Turn Protection	4%
Left/Right Turn Prohibitions	10% *
Right Turn-On-Red Prohibitions	1% *
Approach Directional Flow	9%
Number of Approach Through Lanes	11%
Number of Exclusive Left Turn Lanes	9%
Number of Exclusive Right Turn Lanes	9%
Right Turn Channelization	3% *

*See description below.

An additional complication affected text fields where NULL was an acceptable entry due to software complexities in MIDS. The data collection clerk and the quality inspector were not able to change an entered text field back to NULL. The solution for data collection clerks was to delete all leg data for the intersection and resurvey. As this was not acceptable for a QA/QC solution, these fields were edited using SQL update statements that were not recorded in the log. The missing changes cause the percent error to be too low. For the Left/Right Turn Prohibitions element, this was possible but not a likely error because surveyors were much more likely to miss turn prohibition signs than misinterpret them. The survey team believes the listed percent error for this field is accurate. Based on the quality administrator's familiarity with the data, the Right Turn-On-Red Prohibitions and Right Turn Channelization should be higher by approximately one percent.

Errors in manually collected data occur for a number of reasons. Misinterpretation of data field definitions, misinterpretation of traffic patterns, and surveyor fatigue/inattentiveness are common sources of error. Common errors found in the surveyed data include the following:

- Failure to recognize high occupancy vehicle (HOV) or bus-only lanes as traffic lanes. Many lane counts were missing most likely due to the lack of traffic in imagery and the solid line that usually divides these lanes from normal traffic lanes.

- Failure to recognize exit only lanes as exclusive turn lanes. Many off ramp intersections had GPS locations far from the gore point and given the relatively high zoom level preferred by surveyors, the gore points were often outside the viewing area. Also, pavement marking symbols are not as widely used on the high-speed mainline lanes. The combination of surveying errors led to the perception that all lanes were through lanes.
- Incorrect left turn protection due to definition misinterpretation. Some surveyors focused more on the recognition of traffic signals than the actual definition. They failed to take traffic patterns into consideration at signalized intersections and entered "Permitted" or "Protected-permitted" when there was no opposing traffic. When left turns do not have to yield to opposing traffic the correct option is "Protected."

Step 8: Provide Sample Dataset

The project team provided WSDOT with a series of sample datasets to verify the data structure and the intersection and leg fields were sufficient for their needs. WSDOT team members found errors in surveyed data as well as the data import process and alerted the project team. This process proved to have a very positive effect on the project as it improved data accuracy and communication between the teams.

Results

The focus on user productivity and the intelligent application of geometric mapping heuristics made this project successful despite the complications described above. By the end of the project, user entry rates decreased to 5.2 seconds per question (with the number of questions per intersection varying based on the number of legs, but averaging just over three minutes per intersection). In addition, the abstraction of the geospatial referencing problems allowed for significant reuse of code, even in the face of disparate data sources. This reuse also allowed improvements in the matching heuristics to automatically propagate to all of the specific importers, greatly speeding up the QA/QC cycle for the automated importers.

The entire effort for the Washington State data collection, including the development of the tool and interface, cost approximately $340,000, which FHWA funded through the MIRE MIS Lead Agency Program. Table 9 lists the hours spent on each task, rounded to the nearest five hours.

Table 9. Breakdown of hours by task and total cost for Washington State intersection inventory.

Activity	Hours
Develop detailed Work Plan	425
Develop data collection tool and interface	815
Collect data – manual survey (15,820 spatially distinct State/State and State/local)	2,105
Acquire and incorporate third-party traffic volume data	140
Automated import of existing data from WSDOT source and data aggregation	445
Conduct QA/QC	590
Exporting the final dataset	250
Total Cost*	***$340,000***

**Note:* Total cost is in 2012 dollars and may vary by agency.

Challenges

Definitional Challenges

While the goal of this project was to produce a dataset that followed MIRE guidelines as closely as possible, its intended immediate use as input into *SafetyAnalyst* created some inconsistencies in the way certain elements of the system were defined. Perhaps most glaringly, the *SafetyAnalyst* data model does not contain a concept of interchanges (as distinct from intersections). This created a certain tension on two levels. First, it raised the question of whether or not to represent interchange elements at all. The project team resolved this issue as the absence of this data would represent unacceptably large gaps in the final deliverable. Second, the presence of these elements raised the issue of the applicability of a large portion of the MIRE intersection fields. While these issues were resolvable, that resolution often involved relaxing the MIRE definition by the requisite addition of certain enumerated values.

Inventory Development

The initial creation of an intersection and leg inventory represented a significant hurdle in the early phases of this project. While WSDOT does possess an intersection geodatabase as part of its Roadway Datamart, the use of this dataset as a basis for the intersection inventory proved to be somewhat problematic. This dataset suffers from three significant issues:

1. Spatially coincident records – When two State routes meet at an intersection, they are represented by two spatially coincident records in the WSDOT intersection geodatabase. While reasonable as a matter of bookkeeping (particularly in the absence of a separate leg/approach table), this over-coverage fails to be useful from a data collection perspective. As the data collection process is GIS driven, such records fail to be functionally distinct from a user perspective.
2. Diffuse interchange definition – The distinction between intersections and interchanges presented a challenge with respect to this dataset. Even accounting for the presence of spatially coincident records, the representation of interchanges as multiple intersection records for each road junction produced additional difficulties. The post-processing aggregation of these spatially distinct, but logically joined, records necessitated a simple first pass that aggregated nearby records and then a QA/QC pass that involved manually checking and removing incorrect associations from the aggregated intersection objects.
3. Irrelevant junction entries – The rather late discovery of certain issues with the presence of intersection records that were simply right turn channelization junctions meant that an entire class of records became unusable.

Automated Data Import

Although the presence of multiple data sources helped the effort in terms of coverage, the format and consistency of WSDOT's spatial referencing created some difficult challenges in matching the data to the existing intersection and leg inventory. These challenges necessitated the creation of customized import applications for data source in order to spatially match both point and linestring data to both intersections and legs (while using the attribute matching available to shore up gaps in the spatial matching methodology).

Lessons Learned

1. **Development of a data dictionary:** The process of refining the fields to be collected and the allowable values for those fields created the need for a data dictionary. This method of explicit field definition provided a consistent and traceable medium of information exchange between, and within, the institutions involved in this process, which allowed for the resolution of many questions raised by the data collection team.

2. **Institutional cooperation:** The active involvement of WSDOT in this process was invaluable. The identification of existing data sources, as well as the dedicated work to convert existing LRS-referenced data sources into geospatially referenced data sources saved an immense amount of time and effort.

3. **Design of the database:** The early anticipation of the potential for multiple data sources allowed for a database design that made their representation trivial. While this created questions about the aggregation of these data points in the final deliverable, it allowed all data to be represented in the system at the time those decisions needed to be made.

4. **Use of third party data:** The use of a third party to supply traffic data simplified the issue of traffic data collection. The available resources for this project precluded the possibility of manual collection. Moreover, the dataset provided by the third party contained a projected 2011 average daily traffic (ADT) value that was computed from disparate traffic measures. The decision to use a third party vendor for this data made its collection possible at minimal cost.

5. **Conversion of spatially referenced data**: As mentioned above, some of the best data available were originally not spatially referenced. The project team initially assumed references to an LRS system to be problematic, given the high potential for naming differences to produce mismatch problems. During the assessment phase, WSDOT converted their Signal Maintenance Management System (SIMMS) database into a geospatially referenced dataset, greatly simplifying the process of associating data with our inventory using the same set of tools.

CONCLUSION

The purpose of this effort was to test the feasibility of collecting MIRE data through a Lead Agency Program. Both NHDOT and WSDOT requested an intersection inventory for use in *SafetyAnalyst*, but requested slightly different variables. Having both agencies select similar elements provided the project team an opportunity to compare different data collection methodologies. The project team developed two different tools to collect these data, one simplified tool based on a GIS platform (for NHDOT) and one more sophisticated tool based on proprietary software (for WSDOT).

There were similar lessons learned from both efforts, including:

- **MIRE flexibility:** The primary goal of this effort was to test the feasibility of collecting MIRE data elements. Both NHDOT and WSDOT requested an intersection dataset to import and use in *SafetyAnalyst*. The project team developed data collection tools to populate a database to meet that goal. While the data elements selected were based on MIRE, the data collected required deviations from the MIRE data dictionary in order to tailor them for *SafetyAnalyst*. The flexibility allowed the resulting dataset to best meet the needs of the individual agencies.

- **Development of the Work Plan:** The work plan provided a clear vision and approach for conducting the data collection. Developing the work plan at the onset of the project helped identify clear expectations on the part of the States and the project team.

- **Constant contact/feedback between the contractor and the State DOT:** Throughout the entire process, both transportation agencies were available to answer any questions and to provide clarification and feedback. This constant communication was key to developing a dataset that best met their needs.

- **Use of the sample dataset:** The project team provided a sample dataset to both agencies to ensure there were no problems with the data. This allowed the agencies to identify any potential issues and the project team time to correct them before completing the data collection rather than having to go back and correct the data—thus saving valuable time, budget, and resources.

- **Use of existing data:** The project team was able to derive many of the basic intersection inventory elements from existing data sources; utilizing existing data reduced the time needed for data collection.

There were also differences in the two data collection efforts. The largest differences arose due to the data collection tools themselves. The tool used for NHDOT (based on a GIS platform) took less time to develop, but did not have as many built-in analytical capabilities. The tool developed for WSDOT (based on proprietary software) had more built-in analytical capabilities, including tracking collection; however, it required more time and resources to develop.

There were also differences in the approach. For the NH effort, the project team first imported all of the existing data into the intersection inventory, and then began collecting the needed remaining data. For the WSDOT effort, the project team imported the data into one version of the inventory and collected the data into another version, and then combined them together into one master version of the inventory. The benefit of this approach was that it allowed the project team to conduct the two data collection efforts concurrently (in New Hampshire they had to be done first one and then the other). However, there was more effort spent on the back-end trying to combine the two datasets. Agencies could employ either approach, depending on which method best fit their existing data, needs, resources, and schedule.

The effort to develop an intersection inventory and the data collection tools, as well as determine the implications of the differences in the tools, challenges faced, and lessons learned, provides information that will be of critical importance to agencies when developing roadway inventories in the future. This information will help improve their roadway inventories to better support data-driven decision-making, improve the safety of roadways, and ultimately save lives.

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APPENDIX A—EDIT AND LOGIC CHECKS

New Hampshire Intersection Inventory Edit/Logic Checks

To ensure entry of appropriate values in the data fields, the project team prepared domains based on the *SafetyAnalyst* documentation to provide the user with a drop down menu of acceptable values, as opposed to manual entry that might not have been acceptable for use in *SafetyAnalyst*. The project team did not have any checks on open text box fields except for requiring a number value only (not text) where appropriate. The following sections describe the edit and logic checks built into the attributes, data entry form, and tools.

Attributes/Data Entry Form

1. All fields with a drop down box have set attributes to keep data collection consistent and accurate.
2. Validation to ensure that numeric values are set for open text boxes that require a number. For instance, for Offset Distance, if a text value is entered the user will be alerted once they press OK on the form to save edits that the value is not allowed and a numeric value must be entered before the edits will be saved.
3. Only the fields to be entered or verified by the data entry clerks were enabled; all other fields were disabled. Most of the fields that were disabled were determined from running the model.
4. If the "X" in the top right corner of the attribute form is clicked to close the form before saving edits that were made, the user is prompted if they want to save the existing edits. If they select "Yes," the edits are saved and the form is closed. If they select "No," the form is closed without saving the edits. If "Cancel" is selected the form stays open and the edits are not saved.
5. The attributes that are blank and editable are not required for *SafetyAnalyst* so there are no checks to ensure that those are populated.
6. When a feature has been edited/verified, a field in the database is tagged as such so the project team could keep track of which records had been checked.
7. When a new intersection is created a field in the database is tagged so when the model is run to update the attributes it will know which fields to update.

Tools

1. Only one intersection form can be open at once so the user can focus on one intersection/leg area. If the user attempts to open a second intersection form they are asked if they want to save the edits to the first form before the second form will open.
2. A feature (intersection or leg) is highlighted on the map when its associated form is the active form so the user knows which feature they are assigning attributes for.
3. The layers must be added to the map document and sourced correctly in the XML file in order to edit intersections or legs; otherwise, an error message will pop up.
4. When an intersection is deleted, all associated legs are deleted so that there are no legs without associated intersections.
5. A node must be selected in order to create a new intersection.
6. The update intersection tool will only update a specific set of attributes that may change from year to year.
7. The update new intersection tool will only run against the new records in the database so as not to disturb the records that have already been edited and field verified.

Washington State Intersection Inventory Edit/Logic Checks

The user interface of the MIDS tool had error checks built into the various data entry controls. The project team also conducted additional checks on the data collected through this tool to ensure that the data passed basic logic checks. These additional checks were performed as queries written against the SQL database where the data were stored. The objective of these queries was to isolate bogus data that were not detected at the time of collection. It was most efficient to batch process the queries and review the resulting errors all at once rather than process one query at a time. Most errors found with these logic checks were corrected through the MIDS tool. Some errors were corrected with SQL update statements. A list of the queries and corrective actions taken is as follows:

1) Automatic corrections made with SQL update statements:

    a. If the number of exclusive right turn lanes was equal to zero then right turn channelization has to be NULL.

    b. If the approach has only one lane and it is an exclusive right turn lane then right turn channelization has to be 'No'.

    c. Right Turn-on-Red prohibition was flagged by surveyors signaling that it should be NULL.

    d. Right/left turn prohibitions were flagged by surveyors signaling that it should be NULL.

    e. Once flagged fields were corrected the flags were erased to prevent confusion.

2) Finding NULL records for fields that do not allow NULL values

    a. All valid intersection fields must not be NULL.

    b. The following approach fields must not be NULL.

        i. Traffic control.

        ii. Left turn phasing.

        iii. Directional flow.

        iv. Number of through lanes.

        v. Number of left exclusive turn lanes.

vi. Number of right exclusive turn lanes.

3) Intersection field logic

a. Urban/rural field checked if equals 'Unknown'.

b. Intersection type of 'Ramp/ramp' almost always has intersection geometry of 'on ramp' or 'off ramp'.

c. If intersection geometry is 'on ramp' or 'off ramp' then intersection type has to be either 'Roadway/ramp' or 'Ramp/ramp'.

4) Approach field logic

a. Approach traffic control if NOT 'Signalized' requires:

i. Right Turn-on-Red prohibitions is NULL.

ii. Left turn protection is 'N/A'.

b. Approach traffic control is 'Signalized' requires:

i. Left turn protection is not 'N/A'.

ii. Total number of lanes is greater than zero.

c. If right/left turn prohibitions equals 'No left allowed' or 'No right/left allowed' then:

i. Number of left exclusive turn lanes has to be zero.

ii. Left turn protection equals 'No protection' for signalized approaches.

d. If right/left turn prohibitions equals 'No right allowed' or 'No right/left allowed' then:

i. Number of right exclusive turn lanes has to be zero.

ii. Right Turn-on-Red prohibitions is NULL.

e. If an approach has no through lanes and only exclusive left turn lanes then right/left turn prohibitions is 'No right allowed'.

f. If an approach has no through lanes and only exclusive right turn lanes then right/left turn prohibitions is 'No left allowed'.

g. If number of right exclusive turn lanes is greater than zero then right channelization is NOT NULL.

h. Intersections with a total number of lanes equal to zero has a directional flow of 'one-way'.

i. Intersections should be checked if they have two approaches. Also check those with six or more approaches.

j. No intersections should have one approach.

k. Approach angle (bearing) should be between 0 and 360.

5) Crossing tables to combine intersection and approach field logic:

a. Intersection traffic control has to agree with the approach traffic control of at least one of the associated approaches.

    i. The intersection traffic control should be the highest form of control from the approaches. Examples: signalized, red flashing, and emergency signals take precedence over stop signs and uncontrolled.

b. If total number of legs is three then the intersection geometry cannot be 'four leg' or 'multi-leg'.

c. If total number of legs is four then the intersection geometry cannot be 'Tee' or 'Y'

    i. Also unlikely to be 'on ramp' or 'off ramp'.

d. If total number of legs is greater than four then intersection geometry cannot be 'Tee' or 'Y' or 'Four-leg'.

    i. Also very unlikely to be 'on ramp' or 'off ramp'.

For More Information:

Visit: http://safety.fhwa.dot.gov/rsdp/

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