SCDOT Asset Data Collection Assessment

Final Report

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16. Abstract

The MAP-21/FAST Act requires state departments of transportation to transition to data driven, performance and outcome-based programming, which has required states across the nation to revisit their data collection and maintenance efforts. This report documents research to ensure that the future SCDOT database specifications and data collection efforts support federal requirements for data-driven performance-based management of transportation facilities, as well as meet the needs of SCDOT in a cost-effective manner. To achieve this goal, three specific objectives were established: 1) Identify SCDOT state of practice for asset data collection and maintenance; 2) Conduct vendor rodeo and determine accuracy and cost effectiveness of mobile asset data collection; and 3) Provide specifications for database development and related data collection methods and/or technologies to respond to MAP-21 and SCDOT requirements.

Three main recommendations include: 1) Raise the level of importance of data – treat it as an asset, define core principles, and develop a department-wide directive that recognizes the strategic uses of data across all business offices; 2) Implement a tiered approach to data governance, appoint a dedicated data governance coordinator, and promote structured decision-making and active oversight of the Department's data assets; and 3) Undertake a new inventory of roadway attributes using mobile LiDAR technology to replace the data inventoried 30 years ago, and develop enterprise-wide plans to capitalize on additional opportunities for MLS point cloud data.

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CHAPTER 1: INTRODUCTION

According to the National Academy of Sciences Transportation Research Board (2019), transportation system performance/asset management is among the top critical issues facing departments of transportation today.

> *"…ever growing congestion indicates that the demand for transportation infrastructure is outpacing supply and imposing high costs on society. Limited opportunities and high costs to expand facilities in already congested areas will result in a greater emphasis on maximizing the performance of the existing transportation network. As travel volumes continue to grow and funding remains highly constrained, state and local agencies are struggling to add capacity and maintain the performance and condition of the nation's infrastructure, the value of which is in the trillions of dollars."*

On July 6, 2012, President Obama signed MAP-21, the Moving Ahead for Progress in the 21st Century Act, into law. MAP-21 created a streamlined, performance-based, and multimodal program to address the many challenges facing the U.S. transportation system. The cornerstone of MAP-21's highway program transformation was the transition to a data driven, performance and outcome-based programming. Understanding the magnitude of the shift required by State Departments of Transportation across the country, President Obama essentially extended the provisions of MAP-21 through the signing of the FAST Act, Fixing America's Surface Transportation Act in December of 2015.

In support of this transition, the US Department of Transportation (USDOT) went through a series of public notice of rulemaking and final rules. These rules specify the minimum requirements for performance measurement, data requirements, and plan components. These requirements will undoubtedly drive the redevelopment of databases and management systems throughout DOTs nationally. For instance, as part of the Highway Safety Improvement Program Final Rule, states are required to establish a subset (Fundamental Data Elements – FDE) of the Model Inventory of Roadway Elements (MIRE) for all public roads. On all non-local paved roads, a total of 37 data elements related to roadway segments, intersections and interchanges/ramps are required. Local paved roads require nine roadway segment elements, and unpaved roads are limited to five elements.

A large portion of South Carolina Department of Transportation's (SCDOT) current data is stored in the Roadway Information Management System (RIMS), although numerous other systems in various offices around the state are used to store data that RIMS cannot currently accommodate. SCDOT, like most states, originally developed their RIMS system to support reporting requirements for the Federal Highway Administration's Highway Performance Monitoring System (HPMS) program. Thus, the individual elements contained in the database do not always meet the needs of alternate users in other departments within the DOT. For instance, the presence of roadside parking is important for safety analyses; however, roadside parking is not indicated in RIMS. Instead, roadways with roadside parking are recorded in RIMS as a two-lane roadway with 20-foot lane widths on both sides of the roadway. Over time, other datasets have been merged with RIMS to enable expanded data analytic capabilities including crash information, video log, and traffic counts.

In addition to RIMS, SCDOT maintains several databases to support specific business operations such as maintenance (signs and roadside hardware) and traffic operations (signals and ITS equipment). One example is the e-TEAMS database which houses information regarding traffic signals along state-maintained roadways. The database includes a spatial record of location for each signalized intersection with very basic information regarding the signal itself. Attached to the database are signal plans for many, but not all, of the signals. The database does have a web interface login making it available throughout SCDOT and beyond; however, it is disconnected from the wealth of data contained in RIMS. While electronic access to signal plans is much better than having to locate paper plans, the information in the database is incomplete and plan files must be viewed manually to retrieve information. This practice precludes other offices from easily using signalized intersection information.

SCDOT anticipated that additional data elements and analysis structures will likely be needed to comply with MAP-21/FAST Act. This research would identify new data requirements, level of detail required for each of the data elements, the most appropriate database structure, and the most cost-effective means to capture the data. Determining data requirements requires two foci: 1) ensuring that MAP-21 requirements can be achieved, and 2) ensuring data exists to support SCDOT business processes. Further, the database needs to not only remain dynamically updated, it must also maintain historical information on dates of improvements, types of improvements, project costs, and changes in spatial relations, such as the addition and relocation of roadway segments. Finally, the system will also require governance and financial support.

The **overarching goal** of this research is to ensure that the future SCDOT database specifications and data collection efforts support the MAP-21 requirements for data-driven performance-based management of transportation facilities, as well as meet the needs of SCDOT in a cost-effective manner. To achieve this goal, three specific objectives were established:

- Objective 1 – Identify SCDOT state of practice for asset data collection and maintenance.

- Objective 2 – Conduct vendor rodeo and determine accuracy and cost effectiveness of mobile asset data collection.
- Objective 3 – Provide specifications for database development and related data collection methods and/or technologies to respond to MAP-21 and SCDOT requirements.

The following sections of this report provide details on the activities, tasks, and analysis undertaken to achieve the objectives and provide recommendations for future asset data collection at SCDOT. Over the course of the research, the team members maintained a dynamic literature review document on the state-of-the-art in data requirements, data collection, and data maintenance for asset management which is presented in Chapter Two, as well as in various comparisons and recommendations elsewhere in the report. The methods used in the conduct of the research are reported in Chapter Three. Chapter Four begins with a data gap analysis comparing SCDOT databases to national standards and a listing of prioritized data elements for inclusion in an enterprise data system. The next phase of the project ascertained the technologies that could/should be used to obtain/update data in the system. While many options were considered from digital highway measurement vans, laser measurement systems, and photogrammetry, the magnitude of the data collection led us to focus on Mobile LiDAR Surveys (MLS). No other technology was identified to collect the same magnitude of data at highway speeds with the necessary resolution and accuracy. Finally, Chapter Five includes recommendations for development of guiding principles for data at SCDOT, along with a data governance plan, and technologies for asset data collection of the entire SCDOT road system.

This study evaluated data needs within the department and developed recommended data specifications for a state-of-the-art enterprise data system to support the business SCDOT functions as well as meet requirements of federal reporting mandates. The analysis reported here will aid SCDOT in implementation of an asset data system that meets the department's needs without redundancies and maintaining only data elements that have positive cost-benefit for the department. Having a comprehensive roadway inventory with supporting business data will allow the SCDOT to make better decisions faster, and this should translate to improved effectiveness.

CHAPTER 2: LITERATURE REVIEW

The following literature review sections will cover several topics that are important for developing a comprehensive enterprise-wide asset data collection and maintenance system to support SCDOT business processes as well as meet needs of federal legislation. These topics include MAP-21 and FAST Act requirements, asset inventory state-of-practice, asset data collection, and data metrics.

2.1 MAP-21 / FAST ACT performance metrics and programs

Ultimately, MAP-21 sought to transform the policies and decision-making processes within DOTs to achieve growth, development, and sustainability of the US transportation infrastructure. MAP-21 set requirements for data-driven performance-based and multimodal programs to address the many challenges facing the U.S. transportation system. These challenges include improving safety, maintaining infrastructure condition, reducing traffic congestion, improving efficiency of the system and freight movement, protecting the environment, and reducing delays in project delivery.

2.1.1 MAP-21 Programmatic Requirements

MAP-21 rolled several existing programs into a new core formula program structure which includes:

- National Highway Performance Program (NHPP)
- Surface Transportation Program (STP)
- Congestion Mitigation and Air Quality Improvement Program (CMAQ)
- Highway Safety Improvement Program (HSIP)
- Railway-Highway Crossings (set-aside from HSIP)
- Metropolitan Planning

Two new formula programs were also created: Construction of Ferry Boats and Ferry Terminal Facilities, and Transportation Alternatives (TA). The ferry program replaced a similarly purposed discretionary program, and many of the discretionary programs were eliminated. The transportation alternatives program, with funding derived from the NHPP, STP, HSIP, CMAQ and Metropolitan Planning programs, encompasses most activities previously funded under the Transportation Enhancements, Recreational Trails, and Safe Routes to School programs within SAFETEA-LU.

Along with the formula program restructuring, MAP-21 also required the following four performance plans to be developed and maintained:

- Highway Asset Management Plan for NHS
- Strategic Highway Safety Plan
- CMAQ Performance Plan
- State Freight Plan

While many states have already been tracking assets (e.g., pavements, bridges, and signs), the Asset Management Planning process may expand these efforts. States were encouraged to include all infrastructure assets within the right-of-way. This potentially adds numerous new asset categories such as safety hardware, lighting, signs, and markings. The plans focus on the needs of the state must be recertified every 4 years along with a risk-based asset management plan. As with all plans, the required contents include:

- Asset inventory and conditions on the NHS,
- Objectives and measures,
- Performance gap identification,
- Lifecycle cost and risk management analysis,
- Financial plan, and
- Investment strategies.

From a data perspective, one of the most significant requirements of MAP-21 falls under the Highway Safety Improvement Program, which requires a "data-driven, strategic, and performance focused approach to improving highway safety on all public roads." While the contents of this program are very similar to that of the Asset Management Plan, the assessments are required for **all public roads**. It also specifies the requirement for All Roads Network of Linear Data (ARNOLD), essentially creating a geographically referenced mapping environment for all public roads in the state (i.e., Interstate, NHS, State-Maintained, and City/County-Maintained). These requirements have impacts in association with the data requirements for mapping, inventory, and condition and may require many states to develop data sharing agreements with local agencies.

2.1.2 FAST Act Programmatic Requirements

On December 4, 2015, President Obama signed the Fixing America's Surface Transportation Act (FAST Act), which built upon the changes enacted in MAP-21. The FAST Act had three fundamental goals including improvement of mobility on America's highways, creating jobs and supporting economic growth, and accelerating project delivery and promoting innovation. Several modifications and extensions were included with FAST Act:

- Long range planning and MPO plans are required to include intercity transportation including intercity buses, and planning processes should consider projects and strategies to improve resilience and reliability of the transportation system, stormwater mitigation, and enhance travel and tourism. Planning processes are also required to include ports and private transportation providers.
- The National Highway Freight Program provides funds for improving the efficiency of freight movement on the newly established National Highway Freight Network (NHFN), which includes the Primary Highway Freight System (PHFS) and critical rural and urban freight corridors. States may use limited NHFP funds for public or private freight rail, water facilities (including ports), and intermodal facilities.

- A National Freight Strategic Plan is now required in conjunction with a National Multimodal Freight Network to include NHFN, Class I railroads, inland and intracoastal waterways, ports and airports, and other strategic freight assets.
- The Highway Safety Improvement Program eligible projects were limited to those in the statute (predominantly infrastructure safety-related). However, several activities were added to the list including V2I communication equipment and pedestrian safety improvements. The FAST Act also allows states to opt out of the requirement to collect MIRE fundamental data elements for unpaved roads, but no funds can be used on these roads unless data is collected. Maintenance of ARNOLD and collection of MIRE FDE for all paved roads in the state continues.
- CMAQ funding eligibilities include public transit, bicycle and pedestrian facilities, travel demand management strategies, alternative fuel vehicles, facilities serving electric or natural gas-fueled vehicles (except where this conflicts with prohibition on rest area commercialization) and new eligibility for V2I communication equipment.
- The MAP-21 Transportation Alternatives Program was eliminated and replaced with a set-aside from Surface Transportation Block Grant (STBG) funds which continues to cover smaller-scale transportation projects such as pedestrian and bicycle facilities, recreational trails, safe routes to school projects, community improvements such as historic preservation and vegetation management, and environmental mitigation related to stormwater and habitat connectivity.
- Funding is provided for construction of ferry boats and ferry terminal facilities with weighting determined heavily from ferry passengers.

2.1.3 Transportation Performance Management

The Transportation Performance Management (TPM) and Performance-Based Planning and Programming (PBPP) implementation plans were introduced in entirety in late 2017. The National goal areas include: safety, infrastructure condition, congestion reduction, system reliability, freight movement and economic vitality, environmental sustainability, and reduced project delivery delays. Among these goal areas, there are 18 required measures described in 23 CFR Part 490. The ruling describes the applicability of the measures as well as what data is needed to support them. A listing of the measures follows:

- Five of the 18 measures are related to safety including: number of fatalities, number of serious injuries, rate of fatalities per 100 MVMT, rate of serious injuries per 100 MVMT, and the number of nonmotorized fatalities and serious injuries.
- There are four pavement condition performance measures including: % of Interstate pavements in good condition and in poor condition, and % of non-Interstate NHS pavements in good condition and in poor condition.
- Three system performance measures include: % of reliable person-miles traveled on the Interstate, % of reliable person-miles traveled on the non-Interstate NHS, and % change in tailpipe emissions CO_2 on the NHS as compared to the calendar year 2017 level.

- Only one freight performance measure is required – truck travel time reliability on the Interstate system.
- There are two CMAQ measures: 1) traffic congestion involves Peak Hour Excessive Delay (PHED) measured in annual hours of PHED per capita, and % Non-Single Occupancy Vehicle (SOV) Travel; and 2) on-road mobile source emissions – total emission reductions.
- The last two measures have been reported for some time through the NBI - % Bridges in good condition and poor condition based on deck area.

In addition to the national measures, each state must develop their own state-specific measures and targets for the various other plans on which they are required to report (i.e., planning, safety, freight). The level of reporting is significant, which means that the data systems and analysis requirements are becoming more and more important to the overall business within DOTs.

2.2 Asset Inventory State-of-Practice

2.2.1 Highway Performance Monitoring System (HPMS)

Pavements represent the largest asset maintained by most state DOTs therefore, it is paramount to establish a proper system to manage this asset. The asset management system specific to pavements is referred to as a pavement management system. As with any asset management system, the usefulness of a pavement management system relies on the quality and consistency of the data that populates the system. In a pavement management system, the data of primary interest is the pavement condition data.

In 1978, the FHWA developed the Highway Pavement Management System (HPMS) database to address the mandate that the US DOT report a biennial Conditions and Performance projection of future highway investment needs (23 U.S.C. 502(h)). This data is also used for highway system performance assessment (Government Performance and Results Act, Sections 3 and 4) and for appropriating Federal-aid highway funds under TEA-21 (23 U.S.C. 104).

To support the FHWA's reporting requirement, states (plus the District of Columbia and the Commonwealth of Puerto Rico) are required to provide performance data to the FWHA to populate the HPMS database in accordance with the requirements outlined in the *HPMS Field Manual* (FHWA, 2014). The reporting requirements for pavement condition include: pavement roughness reported as the International Roughness Index (IRI), rutting, faulting, cracking percent (area), and cracking length. Details of each measure are summarized in Table 2.1. There are additional elements that must be reported (e.g., surface type, year of last improvement, year of last construction, last overlay thickness, and others) that are not included in this table because they are not variable with time and, therefore, do not require regular data collection. In addition to the reporting requirements, Table 2.1 also summarizes recommendations for data collection compiled by Simpson et al. (2013).

Table 2.1 Summary of HPMS Reporting Requirements for Pavement Condition

Item	Frequency/ Extent	Measurement Equipment Type	Unit of Measure	Section Length	Standards	Data Collection Recommendations
International Roughness Index (IRI) *(AC & PCC)*	Annual for all NHS Biennial for other required sections	· Sonar · Sonar/Laser · Laser · Scanning Laser · Other	in/mi	0.1 mi	AASHTO R43	· Collection interval ≤ 2 in. · Height sensor footprint width = 2.75 in. · Data collection at same time of day and year
Rutting *(AC)*	Biennial sample sections for all systems	· Sonar · Sonar/Laser · Laser · Scanning Laser · Other/Manual	in	0.1 mi	AASHTO R48 or LTPP Protocol	· Width ≥ 13 ft. · Profile data point separation ≤ 0.4 in. · Longitudinal spacing ≤ 10 ft. · Apply 2 in. moving filter to trans. profile
Faulting *(PCC)*	Biennial sample sections for all systems	· Manual · Laser · Scanning Laser	in	0.1 mi	AASHTO R36 or LTPP Protocol	· Use inertial profiler · Measure elevation at 0.75 in. intervals · Data collection at same time of day and year · Use ProVAL v. 3.3 for calculations
Cracking Percent *(AC & PCC)*	Biennial sample sections for all systems	· Windshield Survey · Visual Distress Survey (roadside) · Manual ID from Video · Automated ID from Video · Manual/Auto ID from Video · Other	% area of fatigue cracking (AC) or % of cracked slabs (PCC)	0.1 mi	AASHTO R55 or LTPP Protocol	· Use automated data collection and processing · Use 100% sampling rate for automated data collection · Manually check ≥ 5% of images for validation
Cracking Length *(AC)*	Optional biennial sample sections for all systems	· Windshield Survey · Visual Distress Survey (roadside) · Manual ID from Video · Automated ID from Video · Manual/Auto ID from Video · Other	ft/mi	0.1 mi	AASHTO R55 or LTPP Protocol	· Use automated data collection and processing · Use 100% sampling rate for automated data collection · Manually check ≥ 5% of images for validation

Notes: AC = Asphalt Concrete, PCC = Portland Cement Concrete

As seen in Table 2.1, there is a wide array of measurement techniques ranging from fully automated to totally manual used for the different items except for IRI, which is now automated. This fact has also been noted in multiple studies of the state-of-practice for pavement condition data collection. In NCHRP Synthesis 439 (Hawkins and Smadi, 2013), 41 states responded to a survey question about the data collection used and the results indicated that 5% used manual data collection methods, 51% used automated methods, and 41% used semi-automated methods. One additional respondent reported using some other type or method. Another study by Pierce et al. (2013) also reported on data collection and processing methods used by a variety of transportation agencies and vendors (Table 2.2). This range in measurement technologies creates a range in the relative confidence of the condition measures reported by different states as summarized in Table 2.3 (Simpson et al., 2013).

Table 2.2 Summary of Agency Data Collection and Processing Methods (Pierce et al., 2013)

	Method	Number of Agencies		
		Agency	Vendor	Total
Data Collection	Automated	23	21	44
	Windshield	19	2	21
Data Processing	Fully Automated	7	7	14
	Semi-Automated	16	14	30

Table 2.3 Confidence Levels for Pavement Condition Measures (Simpson et al., 2013)

Condition Indicator	Confidence in Data
IRI	High
Rutting	Medium
Faulting	Low
Cracking Percent	Low/Medium
Cracking Length	Low

2.2.2 National Bridge Inventory (NBI)

Bridges are a vital part of the infrastructure system and play a critical role in the everyday transportation of road and rail vehicles. Some key bridges are also lifelines in the event of disasters, facilitating the evacuation of damaged urban areas and the movement of emergency vehicles and personnel after extreme events. Based on the ASCE 2013 report card bridges are deteriorating and require immediate attention as well as long term maintenance plans with very limited resources available for maintenance (ASCE, 2013). While there are about 10,000 bridges being constructed, replaced, or rehabilitated annually in the United States at a cost of over $5 billion, the total annual bridge costs, including maintenance and routine operation, are significantly higher (Friedland et al., 2007). As the national inventory continues to age, routine inspection practices will not keep pace with the demands.

Transportation agencies must weigh the variables when determining when and where to spend money. The primary goal of most bridge owners is to prioritize bridge repair and replacement while ensuring all bridges are safe for public use. Every agency has numerous old bridges, many of which are classified as structurally deficient; however, those classifications are often based on subjective data. Bridges are generally rated in the absence of diagnostic load testing information. In some cases, plans are not available which may result in a standard load posting due to lack of information. The current state of the practice for bridge maintenance is based largely on visual inspection (Figure 3.1), which is dependent on the discretion and experience of the personnel. To reduce the uncertainty involved with visual inspection a suite of nondestructive techniques has recently become available. These include diagnostic load testing; wireless self-powered monitoring including strain, temperature, acoustic emission, and other data inputs (ElBatanouny et al., 2014; Godinez et al., 2011); and active techniques such as ground penetrating radar, impact echo, ultrasonics, and others.

Figure 2.1 Visual Inspection Techniques for Bridges
(http://www.fhwa.dot.gov/ research/tfhrc/programs/infrastructure/structures/ltbp/)

inspections of bridges

To take advantage of these new tools, data management software is needed to store and share data between different departments at transportation agencies. Many software tools have become available, such as Life 365 and others to aid in life prediction and management based on differing design and repair strategies. The harmonizing of these tools into current practices such as AASHTOWare Bridge Management Software, formerly ‘PONTIS’, requires proper collection, storage, and sharing of data from visual inspection and other data inputs.

2.2.3 Model Inventory of Roadway Elements (MIRE)

The Model Inventory of Road Elements (MIRE) provides a recommended list of roadway characteristics and important design elements for safety and traffic operations management. MIRE is intended as a guideline to help transportation agencies improve their roadway and traffic data inventories. It provides a basis for what can be considered a good/robust data inventory that helps agencies move towards the use of performance measures. The MAP-21 legislation calls for the establishment of a subset of Model Inventory of Roadway Elements (MIRE) to be collected on all public roadways. This subset of MIRE elements will provide States with roadway data to conduct more rigorous data analyses to support their Strategic Highway Safety Plan (SHSP) and Highway Safety Improvement Program (HSIP). The FHWA Office of Safety issued guidance (FHWA, 2010) that identifies the subset of 37 MIRE elements referred to as Fundamental Data Elements (FDEs). The FDEs are categorized into three components: roadway segments, intersections and ramps/interchanges. For safety management, most of the elements in the inventory are critical for predicting the safety of a section of roadway or an intersection.

The Federal Highway Administration initially distributed the Model Minimum Inventory of Road Elements (MMIRE) in August 2007, mimicking the format of Model Minimum Uniform Crash Criteria (MMUCC). The roadway data specification distributed by FHWA comprised a catalog of data elements for the inventory of roads, along with suggested coding structures (Harrison, et al., 2016). Shortly after the initial release, several changes increased the variable list to about two hundred elements. The MMIRE had turned out to be an all-inclusive inventory of roadway components for collection. Consequently, the term 'minimum' was removed from the title, and the listing is now called MIRE instead of MMIRE. The change was carried out in response to user reviews regarding the total number of features that "minimum" could suggest (Lefler et.al, 2010). The name signaled that the listing of elements had been declared "obligatory.” With the new title, MIRE, it is considered a model representing the nature of the listings of elements containing value-added and critical elements.

The version 1.0 of MIRE was initially released in 2010 to include a list of 202 elements of roadway and traffic data, along with the recommended guidelines. In 2017, FHWA released MIRE 2.0 and significantly enhanced the guidance by receiving input from multiple user groups and comparing the original element listing/domains with those of prominent transportation databases already in use in federally mandated reporting and federally funded tools. Data dictionaries and datasets that were used for this comparison included:

- HPMS – Highway Performance Monitoring System Field Manual, 2014
- TMG – Traffic Monitoring Guide, 2013
- FMIS – Financial Management Information System Users' Guide, 2003
- NBI – National Bridge Inventory, Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges, 1995
- LTPP – Long-Term Pavement Performance Inventory Data Collection Guide, 2006
- NPS RIP – National Park Service Road Inventory Program Cycle 4 and Cycle 5 Data Dictionary
- SHRP 2 RID – Second Strategic Highway Research Program, Naturalistic Driving Study: Development of the Roadway Information Database, 2014
- HSM – Highway Safety Manual, 2010

Noting that collection of the 37 FDEs on all public roads would be challenging for many states, FHWA devised a tiered system based on functional class and surface type. This tiered system has three categories: non-local paved roads, local paved roads, and unpaved roads. The States must have access to all 37 FDE for non-local paved roads, a smaller subset of nine of the FDE for paved local roads, and an even smaller subset of five FDE for unpaved roads. Under certain conditions, States may elect not to collect the FDE on gravel or otherwise unpaved roads, however funds may not be used on these roads until data has been collected.

Building on the release of MIRE, the Roadway Data Improvement Program (RDIP) was designed to help transportation agencies improve the quality of their roadway data to better support safety and other improvement initiatives. The RDIP focuses on the process and practices used by the agency for collecting, managing, and utilizing their roadway data. The MAP-21 legislation requires that States have a Safety Data System that can be used to perform analyses supporting their strategic and performance-based safety goals for their Highway Safety Improvement Program (HSIP). MAP-21 acknowledges the importance of using multiple data sources to understand highway safety problems and making effective decisions regarding resource allocation for highway safety. Further, MAP-21 calls for advancing the capabilities of States for safety data collection, integration and analysis to support program planning and performance management. It addresses the importance of improving the quality of a State's data in terms of its timeliness, accuracy, completeness, uniformity, integration and accessibility.

It is with these goals in mind that the FHWA Office of Safety developed the RDIP. A focus of the RDIP is to help establish performance measures (i.e., data quality metrics) which allow a State to assess how well each component of the roadway data system functions. As strengths and weaknesses are discovered, the State will be better able to address process deficiencies. One of the associated guidebooks (Lawrence, 2012) that has been developed for this program includes the "Benefit-Cost Analysis of Investing in Data Systems and Processes for Data-Driven Safety Programs."

2.2.4 Traffic Control Equipment/ITS

Traffic Control/Intelligent Transportation Systems (ITS) asset management is crucial for expanding real-time traffic operations and management. Many methods have evolved for management of traditional transportation assets such as pavement and bridges. However, ITS is unique due to its diversity of components and the technology-focus, which makes asset management for ITS even more challenging. With several ITS asset management systems available, it is difficult to select the right one and the decision making becomes even more challenging with requirements that are more qualitative than quantitative (Fries, et al., 2004).

Due to the complexity and interconnectivity requirements of ITS, and the variety of system components, asset management for ITS is gaining importance and attention from transportation agencies. Despite this fact, few studies have been conducted addressing ITS asset management systems. Florida Department of Transportation (FDOT) evaluated three customized asset management tools for ITS; OSPInSight, FiberTrak and Fiber management tool for ITS (FMT-ITS). This study evaluated commercial off-the-shelf asset management software based on system architecture, system administration, remote access, user requirements, and reporting capabilities. Overall, this study determined that the FMT-ITS would best serve FDOT's need for managing the ITS assets (FDOT, 2006).

A FHWA study classified signal control asset equipment in seven categories: 1) inventory tracking for field equipment, 2) inventory tracking for spare parts, 3) hardware/software version control, 4) maintenance/work order management, 5) performance monitoring tool, 6) inventory of signal timing optimization/simulation, and 7) inventory of budgeting tool, which can be utilized in a comprehensive ITS asset management system development (Cambridge Systematics, 2004). Several other options exist for transportation agencies to manage their ITS assets. For example, enterprise-based GIS systems and general data management systems such as Microsoft Access are available and have been used for managing other transportation assets. Enterprise-based GIS, with some plug-ins to support ITS asset management, could be a viable alternative to customized ITS asset management systems as many agencies already have deployed enterprise-based GIS tools for managing other transportation infrastructure assets (Fries, et al., 2004). Microsoft Access, or similar, could serve as a data management system when only data inventory is of sole interest. One research has recommended focusing traffic equipment/ITS asset management to a broader view that must include the electronic system components in addition to physical infrastructure elements (Markow, 2008). Although previous work has identified that traffic monitoring systems (Larson & Skrypczuk, 2004), 511 traveler information system and other ITS tools (Cambridge Systematics, PB Consult, & Texas Transportation Institute, 2006; FHWA, 2010; Skolnik et al., 2009) are appropriate for being included in asset management tools, no emphasis was placed on the uniqueness of managing ITS assets. Future research is needed to investigate the return on investment for employing different unique ITS asset management.

2.2.5 Signs and Markings

The 2009 Manual on Uniform Traffic Control Devices (MUTCD, 2009) specifies minimum retroreflectivity standards for different types of signs. Section 2A.08 of the MUTCD provides a standard that: "Public agencies or officials having jurisdiction shall use an assessment or management method that is designed to maintain sign retroreflectivity at or above the minimum levels…" Section 2A.22 of the 2009 MUTCD goes on to say that "Maintenance activities should consider proper position, cleanliness, legibility, and daytime and nighttime visibility." Many states use a replacement practice based on a standard sign age. However, this practice likely removes signs with additional life, while potentially leaving some signs in place with insufficient retroreflectivity that may have degraded faster than expected to the point of insufficient retroreflectivity. To minimize this risk, periodic night time field inspections can be conducted, but these inspections are subjective.

Previous research has shown that computer vision can estimate the visibility of signs from night time video (Maerz, 2003; Carlson, 2011). A primary benefit is that data can be collected at highway speeds. Further, signs locations can be geocoded automatically and potentially stored in a central GIS database. Having a centralized sign inventory can potentially help standardize statewide sign management practices while making the sign inventory available on an enterprise basis. Sign data is useful for a variety of studies including traffic and safety analysis.

Longitudinal pavement markings, which include lane edge lines, skip lines, and centerlines, are the most widely employed traffic control devices. Pavement marking materials provide retroreflectivity to increase safety during nighttime conditions and with impending adoption of minimum national threshold standards (FHWA, 2009), it is becoming crucially important for state transportation agencies to reliably provide and maintain pavement markings within acceptable compliant limits of retroreflectivity.

In 1998, South Carolina Department of Transportation (SCDOT) initiated a research-based project to create a formalized system for evaluating pavement markings along the interstate highway system that would result in safety and economic benefits. As a result, a research project was conducted to quantitatively evaluate pavement marking retroreflectivity at systematic time intervals for the entire 862-mile interstate highway system within the state (Sarasua, 2001; Thamizharasan, 2003; Sarasua, 2002). A similar research project to evaluate durability of pavement markings on primary and secondary roads was initiated in 2008 (Sarasua, 2012; Robertson, 2013; Sarasua, 2013). Prior to these studies, pavement marking replacement procedures were not performance based and SCDOT believed markings were frequently replaced prior to approaching the end of their functional life. A much more serious issue would occur in instances when pavement markings degrade below effective retroreflective limits, posing potential safety concerns. The primary product of both research projects were lifecycle prediction models for pavement markings based on retroreflectivity values. An important input is an initial retroreflectivity value. Collection of pavement marking retroreflectivity at a large scale is expensive and time consuming. A great deal of resources can be saved if an inventory can be collected at the same time as other critical assets.

2.2.6 Multi-modal facilities – freight, transit, ports, airports

More and more states are developing intermodal management systems (IMS). The foundation of an IMS is the development of an ongoing database and a geographical information system (GIS) for spatially referenced data. The database items that are typically included in an IMS are: 1) commodity flows statewide by mode and by network; 2) intermodal network and facility characteristics (i.e. types of runways at airports, number of cranes at ports, geometrics at key intersections and interchanges of highways, ease of transfer between intracity/intercity public transportation); 3) long range freight forecasts; and 4) modal counts (i.e., truck type by facility). The goal of many DOTs is to make the IMS databases accessible to state and regional agencies to provide the necessary data for short- and long-term regional forecasts.

The scope and application of developed or planned IMS vary greatly (FHWA, Quick Response Freight Manual). The following provides a brief overview of the different IMS that have been developed by state DOTs.

- California Intermodal Transportation Management System - The California Intermodal Transportation Management System (ITMS) is a performance-based, decision support system that includes all forms of transportation (e.g., state highways, passenger and freight rail, air routes, waterways, and intermodal facilities). It is designed to assist transportation planning professionals in making informed decisions in selecting cost-effective actions and strategies (e.g., alternatives analysis using performance measures for improving California's intermodal transportation system). The ITMS is an ArcView GIS application that operates on both Windows and Macintosh platforms. It is a macro-level, quick-response planning tool, which has intermodal system elements for person movement. The ITMS links spatial and attribute information for transportation systems for both existing and forecasted conditions.
- Michigan Intermodal Management System - Michigan DOT (MDOT) utilizes an Intermodal Management System (IMS) for integrating its air, rail, marine, transit and non-motorized transportation assets. A great deal of information is stored within IMS; everything from the condition of carpool parking lot pavements, through the capacities of intercity rail and bus facilities, to trends in air- and marine-carried cargo. Some of the asset data go back as far as the 1950s, and all of it is readily available through the use of a normalized database, accessible not only through IMS, but also through a variety of ad hoc query and Web tools.
- Idaho Intermodal Management System - The Idaho IMS includes an inventory and collection of modal traffic flow data. Idaho has divided its data needs into supply and demand categories. Some of the data to be collected on the supply side are: 1) facility location; 2) modes served; 3) hours and frequency of service; 4) capacity; 5) flow rates of persons and goods; 6) industries served; and 7) storage and consolidation capabilities. On the demand side the following information is to be collected: 1) freight characteristics relevant to movement such as density, containerization requirements/opportunities, hazardous qualities; 2) goods and freight vehicle flows on links and through junctions, including intermodal facilities by time and day; 3) origin and destination matrices of person movements and passenger vehicle movements by purpose and with diurnal characteristics; and 4) origin and destination matrices of freight, stratified by type of commodity and characteristics relevant to modal elements.

2.2.7 Construction/Maintenance Costs

Data generated in the preconstruction and construction phases include real estate data (e.g., appraisal document, acquisition date, demolition contract), procurement data (e.g., bid documents, bid tabulations), and field data (e.g., material samples and test results, payment data, daily work reports, change orders). State DOTs are beginning to embrace electronic collection, review, approval, and distribution of construction data and documents in a paperless environment; this process is known as e-Construction. This process has resulted in less use of paper documents but an increase in electronic data. In addition, civil integrated management is emerging as a shift from document-based project delivery and management to a system based on three-dimensional models enabled by technologies such as light detection and ranging (LiDAR) (Sankaran et al., 2016). "CIM is the technology-enabled collection, organization, managed accessibility, and the use of accurate data and information throughout the life cycle of a transportation asset" (FHWA, 2012). Examples of CIM tools and functions can be seen in Figure 2.2Figure 2.3.

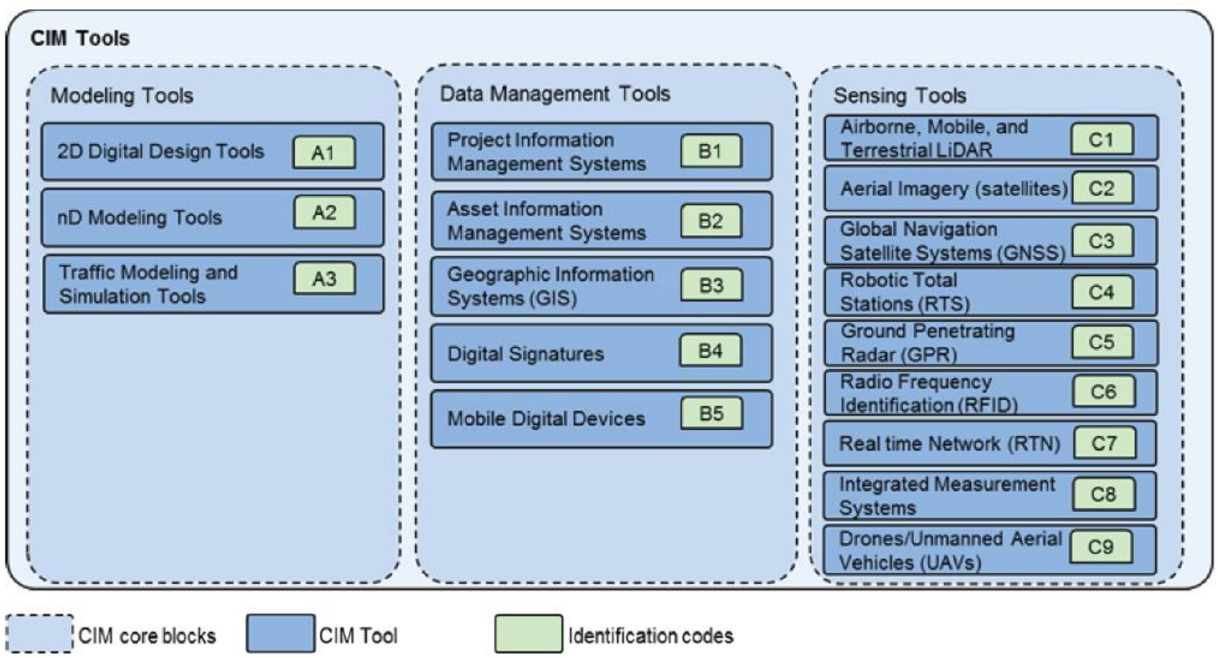


Figure 2.2 CIM Tools (https://www.nap.edu/download/23690)

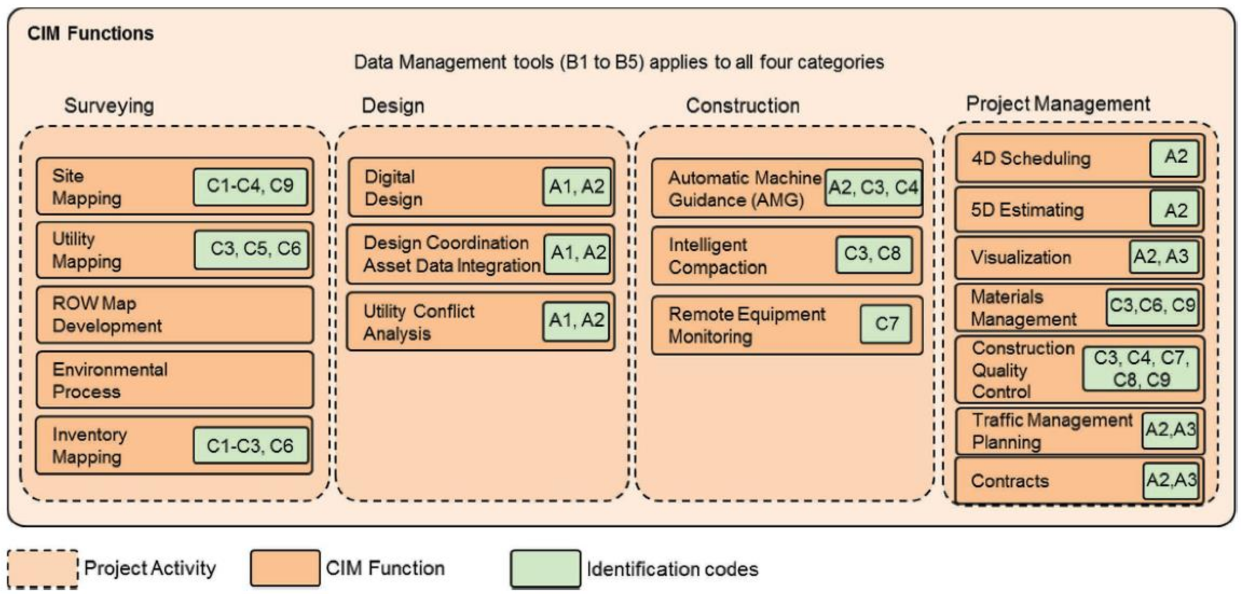


Figure 2.3 CIM Functions (https://www.nap.edu/download/23690)

2.3 Asset Data Collection

In 2008, AASHTO, FHWA NCDOT, and NCSU sponsored a national workshop on Highway Asset Inventory and Data Collection. While the core data emphasis areas were limited to pavements, bridges, roadside elements, and geotechnical features, there were some roadway inventory elements included in the tests. This was one of the first attempts to conduct an evaluation of mobile roadway asset data collection systems. At this point, many vendors were still developing the technologies, and the results were not as expected. However, this study did help establish level of accuracy that could possibly be supported by the current level of technology. This research will also serve as a best-practice for performing vendor rodeo tests. (NCSU, 2008)

During Task 2 of the SHRP 2 research program, researchers (Hunt et al., 2011) developed a prioritized listing of roadway safety data elements and suggested accuracy levels that were necessary for evaluation of the safety of the participants in the Naturalistic Driving Study (NDS). Under Task 3, the research team developed and implemented a plan to evaluate numerous automated data collection firms including:

- Data Transfer Solutions (DTS)
- eRoadInfo
- FHWA
- Fugro/Roadware, Inc.
- GeoSpan
- Mandli Communications, Inc.
- Michael Baker, Jr., Inc.
- Pathway Services, Inc.
- Sanborn

- Tele Atlas; and
- Yotta.

The vendors were provided six unmarked test sites in Northern Virginia along two rodeo routes covering approximately 43 centerline miles. Each route was surveyed three times in both directions. Each of the six test sites was 2500 feet long and included most of the asset types identified in the prioritized list of roadway safety data elements. A variety of land use, cover types, and roadway types were included.

There was an array of responses and accuracies reported by the vendors. Prior to the tests, the research team had established target accuracy requirements for each data element. Upon completion of the tests, they finalized the targets based on achieved accuracies (see Table 2.4 for an example). The results precluded most vendors from proceeding into the SHRP 2 research at the time. Since then, many vendors have been working on their technologies to meet the accuracy standards that were established, and there have been several successful implementations. This table in its entirety provides sufficient metrics for many data elements.

Table 2.4 SHRP2 Roadway Inventory Data Collection Targets and Recommended Accuracies (Hunt, et al., 2011)

Table 3.1. Data Elements for Collection in SHRP 2 Safety Project S04B (continued)

Feature	Data Element	Definition	Rodeo Target Accuracy	CTRE Desired Accuracy	Best Achieved Accuracy	Recommended Accuracy
		Roadway Inventory				
Rail Crossings (continued)	Grade of approach side of crossing	Direction ("+" uphill in direction of travel, or "-" downhill in direction of travel) and Percent of Slope	±0.5%	±0.5%	N/A	±0.5%
	Grade of leave side of crossing	Direction ("+" uphill in direction of travel, or "-" downhill in direction of travel) and Percent of Slope	±0.5%	±0.5%	N/A	±0.5%
Ramps	Ramp location	GPS coordinates of point of ramp gore area	±3 ft	±3 ft	> 4 m	sub-1 m
	Type of ramp terminal	Entry or exit (for roadway on which the vehicle is traveling)	100%	100%	100%	100%
	Type of section	Acceleration lane, deceleration lane, weaving section	100%	100%	100%	100%
Shoulder	Shoulder type	Paved, unpaved, composite (part paved, part unpaved) and curb	100%	N/A	100%	100%
	Shoulder paved width	Width of paved portion of shoulder. Reported from edge line to edge of paved surface to the nearest foot.	±0.5 ft	±0.5 ft (0.15 m)	-0.03 ft	±0.5 ft (0.15 m)
	Shoulder total width	Total width of shoulder (composite only), including paved and unpaved parts. Measured to the first obstacle, or the break in slope.	±0.5 ft	±0.5 ft (0.15 m)	-0.29 ft	±0.5 ft (0.15 m)
	Location of measurement	GPS coordinates of reported data. Reported when the shoulder type changes, or the width changes more than 1 foot, but not in transition areas.	±3 ft	±3 ft	±3 ft	sub-1 m
		Geometric Features				
Grade	Grade in direction of travel	Direction ("+" uphill in direction of travel, or "-" downhill in direction of travel) and percent of slope	±0.5%	±0.5%	-0.164%	±0.5%
	Location of measurement	GPS coordinates of reported data	±3 ft	±3 ft	N/A	sub-1 m
Cross Slope	Location of measurement	GPS coordinates of reported data	±3 ft	±3 ft	N/A	sub-1 m
	Roadway cross-slope	Cross-slope of lane being driven. Direction ("+" slopes toward side of road or "-" slopes towards center of road) and percent of slope.	±0.01%	±0.10%	-0.2045%	±0.2%
Curvature	Horizontal curve PC (point of curvature)	GPS coordinates where curve begins	±3 ft	±3 ft	-154.97 ft	sub-1 m
	Horizontal curve-length		±2 ft	±25 ft (7.62 m)	-17.5 ft	±25 ft (7.62 m)
	Horizontal curve-radius		±25 ft	±25 ft (7.62 m)	128.48 ft	±25 ft (7.62 m)

2.4 Data Metrics

Over the last decade, the Federal Highway Administration has spent a considerable amount of time and research funding to develop and refine the Roadway Data Improvement Program and provide support to states on this topic. In addition, a Supplemental Information Resource Guide was published and includes multiple metrics for data collection, expandability and interoperability, as well as data management and governance. The following sections contain descriptions from the resource guide indicating standards of excellent performance of a mature state DOT system. While these are gold standards that may not be met initially by SCDOT, these are good targets to try to achieve as the SCDOT asset data collection system matures.

Data Collection and Technical Standards

- *Completeness – The State maintains a high-level detail (all required and most desired data elements) for all asset categories for all public roads in the State. The inventory files have very few missing or blank fields (i.e., less than 5%).*
- *Timeliness – The State continually updates all asset inventory files for both new and modified roadways with a process in which descriptions or "as built" plans are submitted to the file maintainer each time a change is made, or a new road is opened. The data for the affected section or locations are then updated to the computerized file within one month of completion of the change.*
- *Accuracy - The State has a high level of accuracy in their inventory data across all categories that they maintain. The existing values are very accurate as determined by a frequent systematic external verification process involving field data collection (e.g., surveys, field visits, and aerial photos). The State also has developed and uses a computerized set of internal verification checks for data reasonableness.*
- *Uniformity – The State has a high level of uniformity and consistency in element definitions and codes. Data coding is consistent across all State and non-State files. Procedures are in place to ensure that coding is consistent across multiple years and to ensure that locations on roadways can be tracked across multiple years.*

Expandability and Interoperability Standards

- *Interoperability – Asset management, safety analyses, and evaluation programs use linked data sets from sources including roadway inventory, traffic, pavement condition, among others. The linked data sets are considered reliable for supporting decision making. Analysis of merged data is a regular feature of analysis.*
- *Expandability - Within the State DOT, modern database design and enterprise-wide planning mean that adding coverage or data elements is built in to systems and thinking about systems improvements. Data transfers among agencies (especially local and State) are primarily electronic and automated as fully as possible. Linkage among systems is accomplished primarily in an automated fashion. Analytic tools are fully integrated and "seamless" access is provided to users. Full spatial analysis capabilities are available.*
- *Linkage - All the key roadway inventory, asset inventories, and supplemental data bases are linked. A single method of location coding is used.*

Management and Governance Standards

- *People - A data governance council or data governance board exists at the State to direct the data management activities of the State. Data champions have been identified in each business area of the State. Organization has "zero defect" (i.e., corrected immediately) policies for data collection, use, and management. People in the state are fully engaged in continuous improvement related to data management and performance measures. Staff members across the state are actively involved in recommending changes for data management policies, standards, and procedures, as business needs change and new performance management goals are identified. Communities of interest, which are comprised of internal and external users and stakeholders for core data programs, have been identified and engaged.*
- *Policies - New initiatives are only approved after careful consideration of how the initiatives will impact the existing data infrastructure. Automated policies are in place to ensure that data remains consistent, accurate and reliable throughout the enterprise. Goals are focused on prevention instead of problem correction. Real-time activities and preventive data quality rules are standard operating*

procedures. A service-oriented architecture (SOA) encapsulates business rules for data quality and identity management. Data metrics are measured against industry standards to provide insight into areas needing improvement. An enterprise Data Business Plan has been developed to support management of core data programs across the agency and has been incorporated into the overall State strategic plan. The State has developed and published a Data Governance manual or handbook which identifies the roles and responsibilities of staff in the state to support data governance operations. It has developed a data catalog with data definitions, standards, policies, and procedures for the collection and use of data in the organization. The catalog is available on an enterprise basis electronically.

- *Technology - Data are continuously inspected – and any deviations from standards are resolved immediately. Ongoing data monitoring helps the data stewards maintain data integrity. The use of technology and tools in the State improves the overall management of programs in the State, in accordance with the strategic mission, goals, and targets. Data models capture the business meaning and technical details of all corporate data elements. Performance management tools, such as dashboards and scorecards, are used in every involved office of the State to monitor the progress of State programs in meeting the State mission and goals. Performance measures and targets are adjusted as needed and displayed on the State dashboard, or similar mechanism, to maintain peak program performance across the State.*

CHAPTER 3:METHODS

The **overarching goal** of this research is to ensure that the future SCDOT database specifications and data collection efforts support the MAP-21 requirements for data-driven performance-based management of transportation facilities, as well as meet the needs of SCDOT in a cost-effective manner. To achieve this goal, three specific objectives were established:

- **Objective 1** – Identify SCDOT state of practice for asset data collection and maintenance (*Data Assessment*)
- **Objective 2** – Conduct vendor rodeo and determine accuracy and cost effectiveness of mobile asset data collection (*Database Gap Analysis and Data Collection Technologies*)
- **Objective 3** – Provide recommendations for asset data improvements to respond to MAP-21/FAST Act and SCDOT requirements. (*Recommendations*)

Several tasks were required to successfully complete the three objectives of this project. The processes undertaken to complete these tasks will be briefly described in the following sections.

3.1 DATA ASSESSMENT

The researchers developed a questionnaire and pre-interview information request that was submitted to primary data managers at SCDOT. The questionnaire focused on types of data that are collected and maintained, as well as sources of data, data format, data storage/access/sharing, and applications of use. Inquiry also covered desirable data that is not currently collected. In addition to the questionnaire, a request for supplemental information was included with the questionnaire to determine if any of the following documents or pieces of information were available:

- Data Dictionaries
- Data Collection Manuals and Procedures
- Data Management documentation
- Data Verification procedures
- Meta-data
- Most up-to-date cost information for maintaining data

Interviews were conducted with numerous data owners within SCDOT. These individuals were intimately familiar with data collection, maintenance, and use. The researchers reviewed existing data in conjunction with office personnel. The team presented information on new MAP-21 requirements, new data analysis requirements, and discussed data needs associated with these and other business processes. Finally, researchers inquired about hurdles, staffing, funding or other that would preclude the database development from moving forward.

Upon receipt of numerous databases, the research team discerned that there was little in terms of supporting documentation at SCDOT. To continue with the research, a tool was developed to determine data specifications and domains for each element in key databases (i.e., RIMS, AADT, and e-TEAMS). The tool returned numerous repeated column headings in various data tables. Online Wordle utilities were used to assess redundant themes among the databases, and filtering was used to study various layers of redundancy and potential causes.

Based on the literature review and interviews with personnel in different SCDOT asset divisions, the research team selected measures of effectives (MOEs) for prioritizing data elements for SCDOT asset management programs. Examples of MOEs included:

- Federal data reporting requirements,
- State or local data reporting requirements,
- Data collection resource requirements,
- Data collection frequency,
- Availability of resources,
- Importance for traffic operational improvements,
- Importance for safety improvements,
- Importance for maintenance,
- Importance for risk management.

Ultimately, the research team in consultation with the steering committee decided to utilize Federal data reporting requirements (pavement and bridge), new MIRE FDE reporting requirements, and importance for traffic operational improvements and safety, as measures of effectiveness for existing state-maintained databases. It required provision of relative weights to MOEs based on their relative importance to SCDOT. Estimates of the relative importance of each data element for different MOEs were evaluated.

In this step, the SCDOT available data is compared to the MIRE, HPMS, and HSM data requirement. The purpose of this analysis was to specify the primary data elements (i.e., FED, FE, and R in MIRE, HPMS, and HSM, respectively) required and to make sure that they are collected by the SCDOT. Data element priority was developed in a tiered system based on these measures, and a multi-attribute utility modeling tool was used to prioritize data elements. This analysis also includes secondary (not primary) data elements, that are either recommended or optional, but not required. In the first round of analysis, most HSM elements fell in this group, but by the end of the project, the research team was able to use elements used in site classification, crash attribution, and safety performance function implementation to determine primary data needs.

Based on this mapping technique, four instances were recognized in a master sheet that reflects various conditions of the data elements collection practiced by the SCDOT, when they are compared to the corresponding data elements in MIRE, HPMS, and HSM. Four color codes have been assigned for different elements based on these criteria. The green color identifies that SCDOT collects and maintains the data elements (either required or optional), while the red color represents data elements not collected and maintained in SCDOT databases.

Finally, the research team selected multiple performance metrics and a weighting criterion to assess the strongest and weakest sections of data.

3.2 DATABASE GAP ANALYSIS AND DATA COLLECTION TECHNOLOGIES

After pouring over the available data and the results of the data assessment, the research team identified significant gaps and issues with the existing data systems. The research continued with a technology assessment. The assessment was limited to Mobile LiDAR Survey based on the age of the last inventory and the scope of need for new inventory elements.

Routes used in the vendor rodeo were chosen in concert with the steering committee. For this project two route segments were planned for inclusion in the rodeo: 1) an urban segment with sidewalks, driveways, lighting, and a variety of traffic control devices; and 2) an approximately 8-mile section of 4-lane highway. The 4-lane highway section was non-interstate divided with relatively low vehicle volumes and very low truck traffic. Both the urban section and approximately 1 mile of the 4-lane divided section was surveyed so that vendor data can be validated.

The researchers established survey controls for the vendor rodeo. Primary survey control (PSC) points were collected and appropriately marked (#5 rebar with a stamped aluminum cap). At least 2 PSC points were inter-visible to establish azimuth. Other control points were established relative to the PSC points using GPS and plane surveying techniques with at least two other control points visible from each control point established. Control points were spaced at intervals less than 1450' throughout the length of the test site. All control points met SCDOT minimum accuracy and precision requirements as set forth.in the SCDOT Preconstruction Survey Manual. NAD 83 South Carolina State Plane Coordinates in International Feet were used for horizontal coordinates. Elevations were based on NAVD 88 and tied to at least one National Geodetic Control Network benchmark.

Once survey control was established, one mile of the alignment was staked using rebar embedded flush to the ground encircled with PVC stakes (rather that standard 36" wooden stakes) along the centerline and each right-of-way line at 100' intervals on tangents and at 50' intervals on curves. PVC stakes are easily labeled, provide resistance to rot and do not have to be offset from the underlying rebar. Important curve locations (e.g., PC, PT, beginning and end of tangent runout and end of superelevation runoff), as well as the beginning and end of bridges, were also staked. Concrete nails combined with reflective pavement marking tape marked lane line points perpendicular to the roadway centerline at each stake location. The reflective tape was easily identifiable in the mobile mapping laser data because the reflective amplitude values are much higher than ordinary pavement. Elevations and coordinates were collected at all of the taped locations. The coordinates and elevations of all transportation assets prioritized for data collection were determined through manual surveying. These assets included signs and markings, guard rail and other roadside safety devices, culverts and other storm water elements, luminaires, bridge elements, and distressed pavement among others. Detailed traverse profiles were surveyed at selected stations to test the sensitivity of the mobile systems to undulations in the pavement surface (e.g., rutting).

The planimetric assets were manually located along the 1-mile segment precisely through conventional surveying and mapped in a GIS database. SCDOT surveyors and the steering committee were given the opportunity to inspect the test site before the vendor rodeo.

Upon soliciting leading vendors of scanning technology for mobile asset management data collection to participate in a rodeo focused on replicating real-world data collection environments, a data collection, comparison, evaluation and documentation plan was developed and submitted to SCDOT for approval before releasing to prospective vendors. The plan included test section sites for collection of right of way asset inventories and roadway data elements. The plan also included target levels of accuracy to be achieved for each data element. These target levels were chosen based on prior studies and needs of SCDOT. Prospective vendors were allowed an opportunity to review and ask questions. Modifications to the data collection plan were made as needed.

SCDOT assisted with traffic control and safety aspects of conducting the rodeo. The vendors had the opportunity to calibrate their systems and make a single pass in each direction through the test section. Vendors were asked to provide a point cloud with attributes (e.g., elevation and amplitude) in a specified format for delivery that was identified in the original request. Additionally, participating vendors were asked to extract right of way asset management asset data and roadway elements at specified locations.

Results from automated/mobile data-collection services were evaluated and documented based on a wide range of comparisons including coverage, consistency, completeness, and accuracy.

Vendor systems were evaluated based on a range of criteria including coverage, consistency, completeness, and accuracy, as well as a comparison of mobile system alignments and inventories with the surveyed roadway data elements. Another criterion was the ease at which assessment management data can be extracted from the point cloud. The ability to accurately link photologged images with the laser data was also evaluated as well as the conversion of collected data to Bentley Microstation and Geopak design files.

3.3 RECOMMENDATIONS

Over the last decade, the Federal Highway Administration has spent a considerable amount of time and research funding to develop and refine the Roadway Data Improvement Program and provide support to states on this topic. In addition, a Supplemental Information Resource Guide was published and includes multiple metrics for data collection, expandability and interoperability, as well as data management and governance. Descriptions from the resource guide indicating standards of excellent performance of a mature state DOT system were included in the literature review. While these are gold standards that may not be met initially by SCDOT, these are good targets to try to achieve as the SCDOT asset data collection system matures. These standards and a thorough review of literature provided the framework for the recommendations to meet the goal of the project – to ensure that the future SCDOT database specifications and data collection efforts support the MAP-21 requirements for data-driven performance-based management of transportation facilities, as well as meet the needs of SCDOT in a cost-effective manner.

CHAPTER 4: RESULTS

4.1 Data Assessment

4.1.1 Review of SCDOT Data Collection and Maintenance Practices and Policies

The Office of Road Data Services was interviewed to ascertain information about assets related to the state transportation infrastructure. Questions for this group related to structural aspects of the state data system, as well as ongoing data collection and maintenance efforts. Additional meetings were held with various offices regarding other asset inventories managed across the state (either centrally, or at the district level). Finally, the team members provided feedback associated with access to data for prior projects and the utility of those data for departmental needs. These discussions highlighted numerous positive aspects of the existing data infrastructure as well as many that are can be considered opportunities for improvement. These points will be highlighted in the sections to follow.

4.1.1.1 LRS and Basemap

The Road Data Services Office maintains various GIS features within an Oracle database that make up the entirety of the base map which connects directly with the state road inventory file. Updates to this information occur monthly as roads are added, removed, renumbered, or modified. There is physical line work for separate directional segments for interstates; however, the operationalization is still based on one bi-directional segment and the directional segments mirror the same length. The segments break at each state/state intersection, but some local intersections are not indicated in RIMS (see Figure 4.1). All ramps and interchange connections are also available in the line network. Figure 4.2 provides an example of the pavement status data contained in an open online portal. The portal allows users to select a road segment to determine the LRS and milepoint information, and linework represents whether the link is paved or unpaved as well as whether it is maintained by the state or other public entity. The availability of this data online is a great step toward data sharing and transparency.

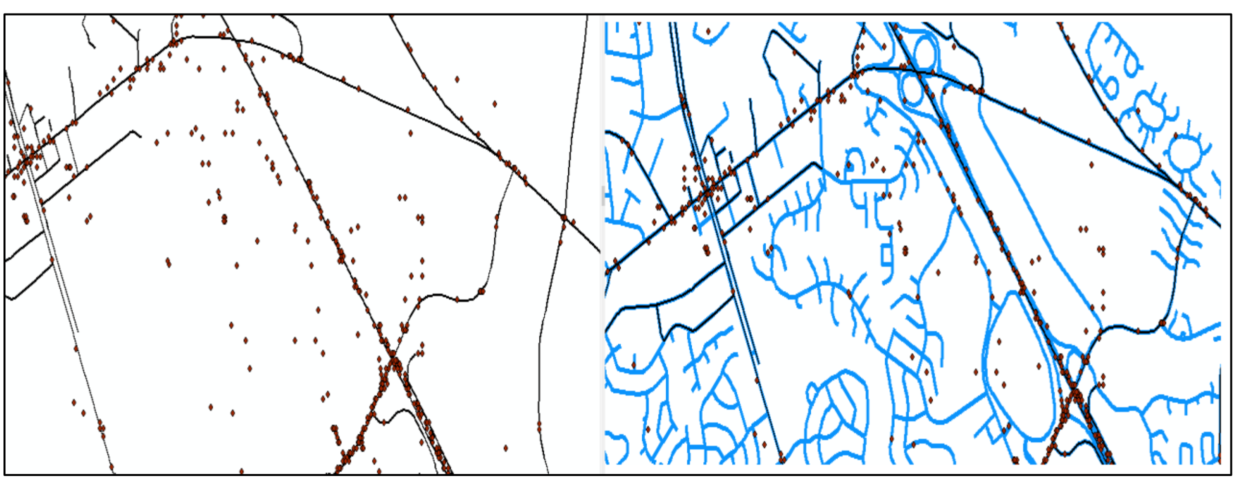


Figure 4.1 State maintained RIMS (left) and State + Locally maintained Networks (right)

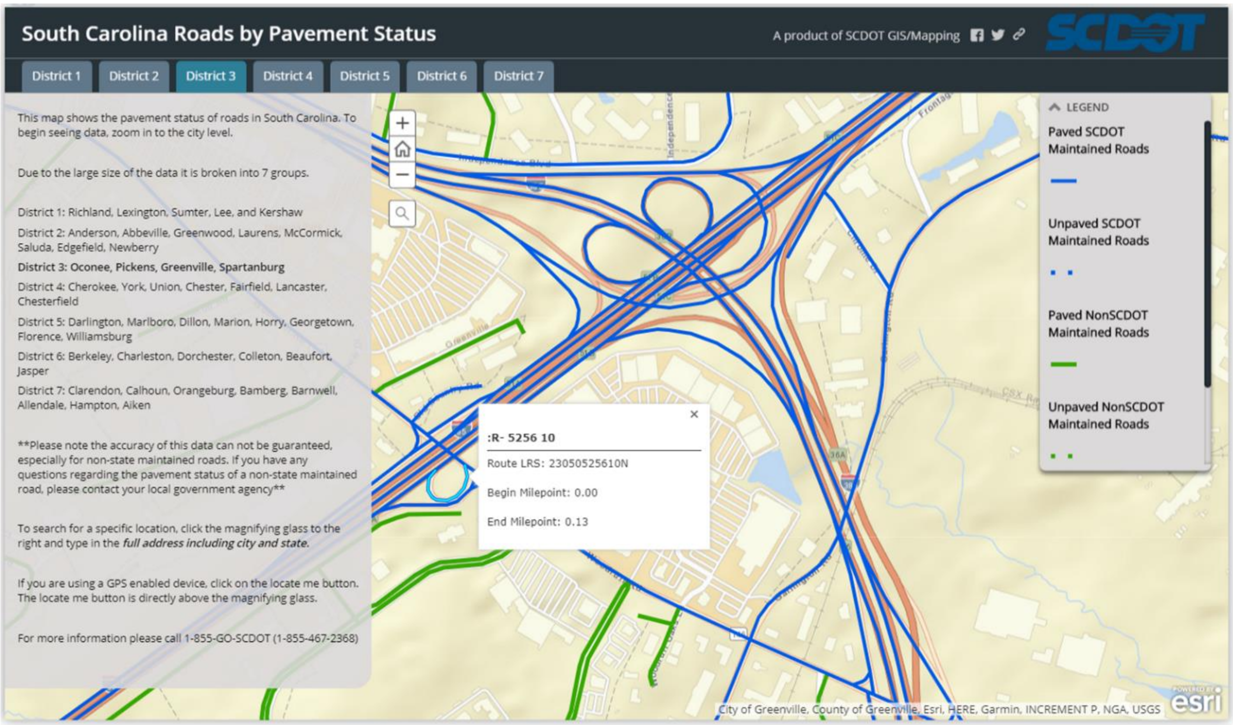


Figure 4.2 Example of South Carolina Roads by Pavement Status Online Portal

SCDOT maintains a single uniform linear referencing system (LRS) which consists of a county, route type, route number, and route auxiliary classification system. Exact locations along the linear referenced segments are found using milepoints. For example, US-1 mainline in Aiken County has an LRS of 02020000100. The first two characters represent the county (Aiken county = 02), the next two represent the route type (02 = US), the next five are for the route number, and the final two characters are for the route auxiliary (00=mainline). SCDOT has recently developed a translation tool to allow for conversion between GPS (latitude and longitude) data and LRS (for internal use only). The extent of the road network includes all roads open to the public (over 76,000 miles), which covers everything but private roads.

In terms of the compliance with All Road Network of Linear Referenced Data (ARNOLD) Legislation, SCDOT has met the minimum requirements by providing an intersection-based network and utilizing a dual-carriageway representation for divided highways. The start and end of ramps have been defined with respect to the taper length; however, deceleration and acceleration sections are not identified as separate LRS events. Further, independent mileage calibration is not provided for dual-carriageway routes. ARNOLD guidance also suggests having policies for modeling traffic circles, cul-de-sacs, and loops as these features can have numerous segments, overlapping segments, and may be problematic in GIS software packages because they can have the same starting and ending points.

MAP-21/FAST Act reporting requires network information for Intermodal Facilities, freight networks,

Key positives – SCDOT has an ARNOLD compliant basemap and a single uniform LRS that is accepted as a statewide standard.

Key opportunities – Develop documented update procedures for LRS and basemap because none currently exist. Although, the basic parameters for ARNOLD compliance have been met, consider additional adoption of guidance with respect to ARNOLD, as these represent best practices (i.e., dual carriageway mileage, separate acceleration and deceleration segments, traffic circle segmentation, and coding of cul-de-sacs and loops among others).

4.1.1.2 Roadway Inventory

The Road Data Services Office maintains the Roadway Inventory Management System (RIMS) database which resides alongside the basemap in Oracle. This is the formal inventory management system for SCDOT, which is dynamically updated with new information within approximately two-weeks of receipt of a change record. A historical snapshot of RIMS is taken at the end of every year in December capturing all the changes that occurred since the prior snapshot. Roadway inventory attributes are referenced using the LRS and nearly 200 characteristics are contained in a single tabular format. Changes in any of the nearly 200 characteristics create new beginning and ending milepoints. Currently, data are only available for state-maintained roads except for city and county roads that are part of the HPMS sample frame. The original data from which the inventory is based is over 30 years old. While inventory is updated monthly using project plans, physical inventories are not regularly performed unless needed. Keeping up with changes is challenging, especially for projects that are not funded directly through SCDOT (e.g., county sales tax projects) and files not shared in a timely manner.

There is an internal web viewer called the Integrated Transportation Management System (ITMS) to access the roadway inventory data. Using this viewer, county maintenance personnel and other SCDOT staff may report data that they believe are inaccurate using a button to capture the map and text entry. However, this type of information gathering is unreliable. It is up to the reporting individual to report the error, and the Road Data Services Office to take corrective action and verify the new information. All changes that are made to the data are logged in a document ledger system maintained in Project Wise. Further, SCDOT does not maintain a data dictionary for the RIMS database, so users may be uncertain as to whether the coding is in error or if they are not aware of the proper code designations.

A listing of all intersecting elements on each LRS segment is available and includes: bridges, railroads, state lines, other roads, among other entities. The intersection lookup tool is shown in Figure 4.3 along with sample data. As mentioned previously, the existing intersections are limited to state/state and some state/local – thus, not all intersections are identified. During the period of conduct of this research, SCDOT began a Local Agency Data Collection (LADC) process to get county/city GIS road data files to be conflated into the RIMS along with attributes (e.g., length, intersections, and pavement type). Through the LADC process, SCDOT obtains GIS files from counties and cities to fill in these gaps. The first step in the process is to locate each route and break existing SCDOT LRS segments to create intersections between the two routes. The creation of two new LRS segments requires new LRS numbers for the new sections, as well as route numbers and LRS identifiers for the newly added roads. This process is conducted using Geomedia software. The final tables with the new information are brought into RIMS. At the time of reporting, a few counties remained to be completed through LADC.

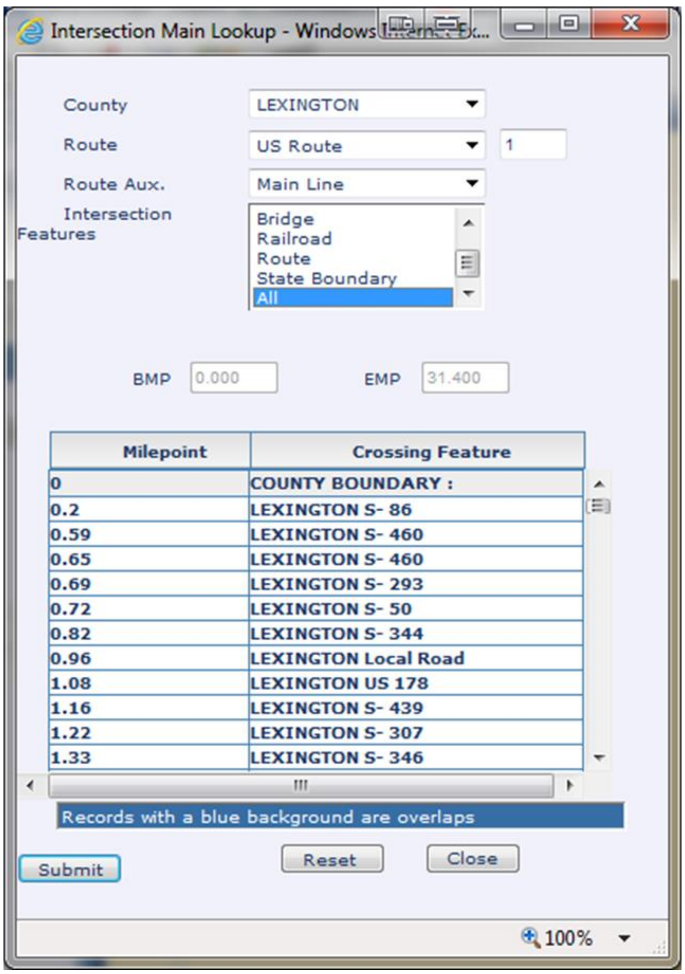


Figure 4.3 Intersection Lookup Tool in RIMS

Key positives – SCDOT maintains a roadway file on a statewide platform with an internal network accessible viewer (ITMS), dynamically updates the file when new data are identified, and archives a snapshot on an annual basis.

Key opportunities – The original road inventory data collection was conducted over 30 years ago and the state is long overdue for a full inventory data collection effort. A data dictionary is needed *so that everyone knows all elements contained in the file along with respective domains. The single flat file database structure is cumbersome and could be replaced with asset-based files more common in geographic information systems. Finally, most of the SCDOT data collection efforts are focused around the HPMS program which has been in place for a long time, and by its very nature is biased toward higher functional classification roadways. A significant percentage of the network (secondary and local) is only sampled in the data collection process; thus, leaving large gaps in data for all public roads.*

4.1.1.3 Other Asset Databases

The state maintains several asset inventory databases beyond the purview of the Road Data Services Office. Each functional office collects and maintains their own data. For example, Pavement Management collects pavement condition data and images for Highway Performance Monitoring System reporting. The Maintenance Offices collect culvert, sign, and guard rail data at the district level and combine them into a statewide file. Traffic Engineering collects traffic signal equipment inventory and timing plans and populates the data in e-Teams. Additional inventories include outdoor advertising, overhead signs, oversize/overweight permitting truck routes, encroachment permits for driveways, Right-of-Way, and the Interstate plan library.

Most of the inventories are based on the standard LRS, and many also include GPS. However, it was unclear whether the databases maintained outside of Road Data Services Office are keeping pace with dynamic changes in the LRS, or even updating the LRS data on a regular basis. For instance, Figure 4.4 shows the coding for Primary, Secondary, Third Route, and Fourth Route associated with each signal location. Note that all of the data needed to obtain the LRS are included (county, route type, route number, and milepoint), however, linkage with other databases at the state is more difficult because route LRS are not maintained. Assuming the asset databases share the same version of LRS data, the integration of the two is simple. However, without a common platform, sharing data will require redundant copies and may generate potential errors when merging with other sources. Further, in all discussions, no one was aware of a common comprehensive listing of the data collected by each office, the attributes available, or the quality and completeness of the databases. The database systems available for viewing through ITMS are: RIMS Road and Bridge data as well as traffic count data, HMMS Sign inventory and Daily Work Report data, TEAMS traffic signal location data, Pavement Resurfacing and Preservation Candidate Lists, Additions Viewer showing when roads are added or removed from the state system, Dedicated Roads Viewer showing all the road and bridge dedications around the state, Photolog, and Road Conditions showing of all the SCDOT activities which affect the normal flow of traffic (e.g., lane closures due to a construction project).

Table

SC_SG_Int_eTEAMS

FID	Shape	County	City	Primary_Ro	Secondary	Third_Rout	Fourth_Rou	Is_Master	In
2	Point	Darlington		US52 Business MP: 1.70	S-69 MP: 0.001	Main St	Orange St	X	X
3	Point	Chester		SC9 MP: 38.553	S-19 Ramp MP: 0.039				
5	Point	Anderson		SC153 MP: 4.461	Old Pendleton Rd MP:	S-94 MP: 2.692			
25	Point	Richland		S-63 MP: 0.671	I-20 MP: 76.139	Alpine Rd MP: 0.67			X
26	Point	Anderson		SC24 MP: 13.76	Michelin Blvd				
27	Point	Anderson		SC8 MP: 5.593	I-85 MP: 31.738				
35	Point	Chesterfield		SC9 MP: 34.334	S-51 MP: 2.397	Four Mile Loop Rd			
40	Point	Lancaster		SC9 Business MP: 3.54	S-45 MP: 0.679	Meeting St E	Wylie St MP: 0.679		
41	Point	Aiken		SC125 MP: 8.506	Sheraton Dr	S-1463	Atomic Rd MP: 8.5		
48	Point	Dillon		SC9 MP: 10.928	Enterprise Rd	Bradford Blvd			X
49	Point	Dillon		2nd Ave	Main St W	US301 MP: 10.528	US501 MP: 6.9420		X
56	Point	Richland		US176 MP: 17.044	S-1280 MP: 1.254	Piney Grove Rd MP:	Broad River Rd MP		
57	Point	Anderson		SC8 MP: 8.824	SC81 MP: 35.762	Moore Rd			
60	Point	Newberry		SC34 MP: 21.797	Adelaide St MP: 0.369	S-383 MP: 0.369			
62	Point	Chester		SC9 Business MP: 1.71	S-272 MP: 0.097	S-6 MP: 0.129	Church St MP: 1.7		
65	Point	York		SC55 MP: 17.458	S-54 MP: 1.549	Church Park Dr	Paraham Rd		
74	Point	Horry		US17 ByPass MP: 3.777	Glens Bay Rd	Holmestown Rd MP	Mark Garner Hwy		
75	Point	Richland		US1 MP: 13.099	S-1274 MP: 3.179				X
95	Point	Richland		S-127 MP: 1.756	S-435 MP: 0.726	Covenant Rd	Bethel Church Rd		
96	Point	Lancaster		SC9 Business MP: 4.08	S-136 MP: 0.37	White St	Meeting St E MP:		X

0 (0 out of 4012 Selected)

SC_SG_Int_eTEAMS

Figure 4.4 Snapshot of data contained in e-Teams database

Key positives – Numerous functional offices at SCDOT contain data champions and prioritize funding for asset data collection to meet business needs.

Key opportunities – All asset data should be integrated into ITMS with access statewide to allow for the most efficient and effective use of SCDOT investments and decision-making. The data owners should still be responsible for the collection and maintenance of data for their business needs, however, duplicated items should not be collected by more than one office – collect once, use many. Development of data dictionaries will aid in identification and removal of duplicate data items.

4.1.1.4 Governance and Standards

There is a group of individuals in the Roadway Data Services Office, Information Technology Office, and in functional offices in the SCDOT that keep the agency current with federal reporting requirements. This group has extensive expertise and are good stewards of SCDOT funds within their respective areas. However, there is not an oversight group that ensures that decisions are made with respect to which data elements need to be collected and maintained by the enterprise, where overlap and cost savings can be found, where redundancies can be eliminated, and which data sources are the most critical needs of the department.

In the past, ad hoc groups have been formed for activities such as prioritizing which elements would be integrated into ITMS. There was also an IT Steering Committee under a prior Commissioner. These types of groups bring representation from across a department to make critical data decisions on behalf of the enterprise, develop strategic plans to build the enterprise data system, streamline functions and processes, as well as bargain for efficiency and interoperability. If one office seeks a data collection contract for a specific element, it is probable that the contractor could collect additional elements for little additional money, because the main cost is associated with sending the data collectors around the state. However, if each office must fend for themselves, and there are not occasions or opportunities to plan in conjunction with other offices, there will be duplicative efforts and more money will be spent.

The lack of oversight also affects data standards – especially uniformity/consistency and accessibility. Overall, it would be hard to indicate the completeness and timeliness of all SCDOTs many asset databases. Each has a different owner, as well as a different view of the level of completeness and accuracy required for the job at hand. Whereas, when developing an enterprise system, these metrics are agreed upon before the system is developed, to ensure that it meets the needs of most core users. For instance, Roadway Data Services is responsible for fixing issues that are reported via the ITMS error report feature. This is built into the daily work of the group. Also, RIMS data is processed for uniformity and consistency through validation checks to ensure that route numbers exist, and numeric data are within an appropriate range. Accessibility is also foremost in an enterprise database, because the data has been deemed to have value to the department. Therefore, the whole department should have access as needed. In addition to internal users, accessibility can be assessed for external users. While not containing all SCDOT assets, a new Open Data Sharing portal has been developed with data from RIMS and ITMS are available to the public with free online access (see Figure 4.5).

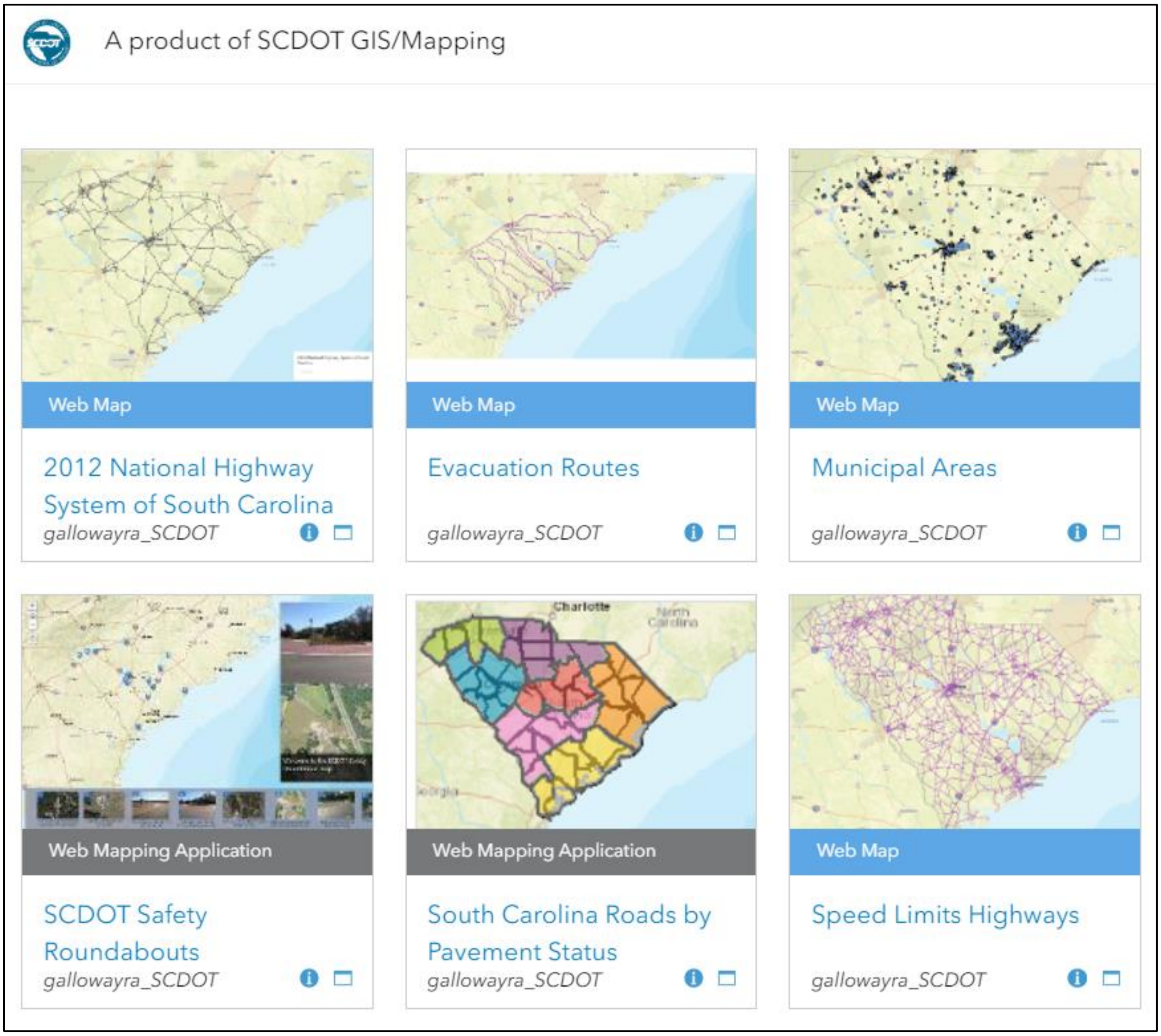


Figure 4.5 Open Data Sharing Portal – Example of Maps Available
(Source: http://scdot.maps.arcgis.com/apps/MinimalGallery/index.html?appid=e8ace63de0e6423394d04c9c091e893b)

Key positives – The Roadway Data Services and Information Technology Offices have championed the common LRS as a standard within the department, and most other offices are using the LRS in their data processes. Numerous offices within SCDOT have developed and maintain data systems to meet federal reporting requirements and deliver transportation services in the state.

Key opportunities – There is not a coordinated group at SCDOT led by a data champion with a vision, a charge, and a budget to implement a state-of-the-art enterprise data system. The roadway inventory was collected over 30 years ago but has not been consistently updated. When errors increase, trust in the data decreases, and employees will skip the databases and collect their own data in the field. There is insufficient documentation on databases, which creates a steep learning curve. If it is too difficult to use the data, decisions may not be data driven. Disparate databases *maintained in offices throughout the DOT are not easily accessible or integrated. Data integration often requires data and IT expertise which increases time to receive data and decreases overall efficiency. Further, all the disparate databases contain some portion of LRS and RIMS data – meaning data are duplicated across the agency in different business units. When this occurs, there is opportunity for conflicting data, and storage and personnel costs also go up.*

4.1.2 Collect, Review, and Document Existing SCDOT Databases

During the project, project team members requested information on numerous databases maintained by SCDOT and received samples of many but not all the identified databases. From the following data areas, the bolded databases were received and extensively analyzed.

- **Traffic (HPMS)** and Pavement Preservation
- **Bridges (NBI)**
- **Roadway Inventory (RIMS, MIRE/FDE)**
- **Traffic Control**/ITS **(e-TEAMS)**
- Multi-modal Facilities (**Railway**/Port/Airport)
- Maintenance, **Signs**, Markings, Guardrail (HMMS)
- **Safety (Crash/MMUCC)**
- **ITMS**

4.1.2.1 Database Dump Summary

The quantity of data files received from the ITMS system alone required the research team to develop a summary tool to capture the file name, file size, number of worksheets, number of rows, number of columns, and the respective column headings. The data dump contained 437 files and consisted of over 16 GB of data. Over 58 million rows of data and almost 9,000 columns were summarized. Figure 4.6 contains a sample of the data dump summary file and the complete worksheet is located in Appendix A.

Name	Size (MB)	Sheets	Rows	Columns	Headers 1	Headers 2	Headers 3	Headers 4	Headers 5
DOM_RTE_SYSTEMS_102215.xls	41.19	2	114,543	37	DOM_RTE_LRS	DOM_RTE_BMP	DOM_RTE_EMP	DOM_BMP	DOM_EM
DOM_SPD_REG.xls	1.54	1	8,905	12	DOM_RTE_LRS	DOM_RTE_BMP	DOM_RTE_EMP	DOM_BMP	DOM_EM
DOM_SPD_REG_HIST.xls	0.04	1	140	12	DOM_RTE_LRS	DOM_RTE_BMP	DOM_RTE_EMP	DOM_BMP	DOM_EM
DOM_TRAF_ORIGINAL.xls	16.97	2	90,772	16	DOM_RTE_LRS	DOM_RTE_BMP	DOM_RTE_EMP	DOM_BMP	DOM_EM
DOM_TRAF_TDS.xls	174.43	4	238,833	89	ERROR_NBR	TERMINI_DIFF	COUNTY_ID	DOM_RTE_LRS	DOM_RTE
DT_AADT_NON_COVERAGE.xls	0.04	1	481	5	YEAR	FUNC_CLS_ID	FACTOR_TYPE	MONTH	FACTOR
DT_ADDN_ACTNS.xls	17.34	1	59,957	13	ADDN_ACTN_ID	COUNTY_ID	ADDN	ACTN_ID	COMMISS
DT_ADDN_RTES.xls	10.02	1	64,859	9	ADDN_ACTN_ID	RTE_LRS	BMP	EMP	SECTION_
DT_BRIDGE_AADT.xls	0.01	1	2	3	NBI_008	COUNTY_ID	STATION		
DT_CITIES.xls	0.06	1	277	11	CITY_ID	IS_OBSOLETE	CITY	IS_INCORPORATED	FIPS_CITY
DT_CITY_COUNTY.xls	0.03	1	307	4	CITY_ID	COUNTY_ID	UPDT_BY	UPDT_ON	
DT_COGS.xls	0.01	1	11	6	COG_ID	COG	IS_OBSOLETE	COG_ALT_ID	UPDT_BY
DT_COG_COUNTY.xls	0.02	1	47	4	COG_ID	COUNTY_ID	UPDT_BY	UPDT_ON	
DT_COLL_DIAGRAM_CRASH_IDS.xls	1.47	1	31,491	3	HEADER_ID	CRASH_ID	LEG_ID		
DT_COLL_DIAGRAM_EXCLUDE.xls	0.02	1	178	2	CRASH_ID	LOCATION			
DT_COLL_DIAGRAM_HDR.xls	0.11	1	935	8	HEADER_ID	BEGIN_DATE	END_DATE	CITY_NAME	COUNTY_
DT_COLL_DIAGRAM_LEGS.xls	0.33	1	3,035	7	HEADER_ID	LEG_ID	DOM_RTE_LRS	DOM_BMP	DOM_EM
DT_COUNTIES.xls	0.02	1	49	9	COUNTY_ID	COUNTY	FIPS_COUNTY_ID	DISTRICT_ID	HURR_EV

Figure 4.6 Sample of ITMS Data Dump Summary File

One of the key findings from this exercise is that there are a lot of duplicate fields across several data tables as indicated by the column headers coded in each row with the respective database filename. Using the headers as data input, several word art files were created to discern the magnitude of duplicate terms across the individual data tables. Figure 4.7 provides a sample of the word art file created using no filters. It is clear, that update tracking across many files is important, but not indicative of the types of duplicate field headers that the research team is looking for. Another program was used to create the word art that allowed the word list to be filtered and a minimum weight set for duplicate entries (see Figure 4.8).

Figure 4.7 ITMS Data Dump Summary of Field Headers - Word Art Version 1

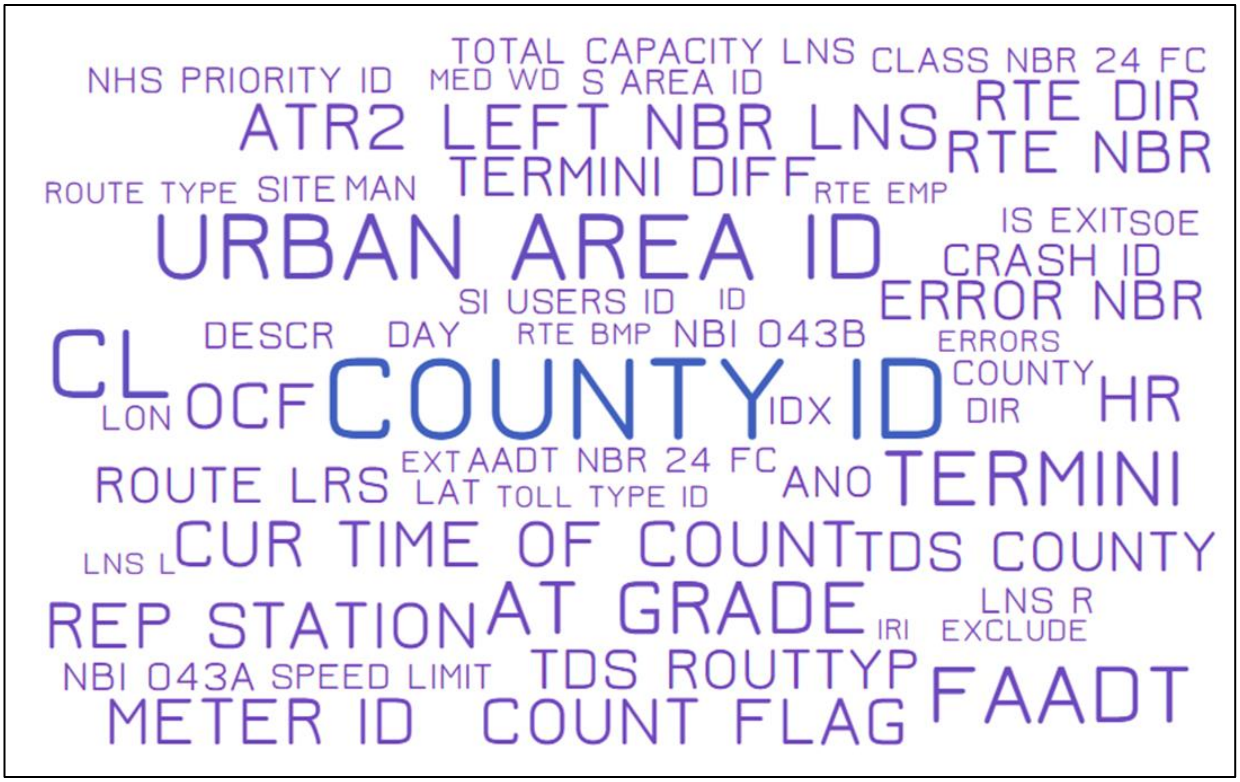


Figure 4.8 ITMS Data Dump Summary of Field Headers - Word Art Version 2
(Filtered Updated On and By Headers, min weight = 16)

The second version of word art indicates a clear focus on the Highway Performance Monitoring System. There are numerous HPMS data tables for various years of data as well as Count Station files which contain similar data – thus the repeating headers from one file to the next. The final word art was generated for all column headers that had any number of duplicates. This word art can be found in Figure 4.9. Again, the focus on HPMS in the RIMS files is clear, but the key finding from this graphic is the sheer number of fields that are duplicated. Data redundancy is good when you are considering the main data source and it's back up file. However, similar columns of information in similarly named tables can be troublesome, especially if there is not a good description for each table and the data contained within (i.e., meta data and data dictionaries).

Recall that these word art files were generated only from data contained within RIMS. Had all the asset databases from SCDOT been included, the redundancy would appear even stronger. During conversations with various offices that maintain databases separate from RIMS, it was discovered that they also maintain various features from RIMS data files to make it easier to merge, query, and analyze data for reporting and business purposes. Redundant data is expensive to maintain, diminishes the trust in the authoritative database if errors are found in duplicate copies, and create personnel inefficiencies.

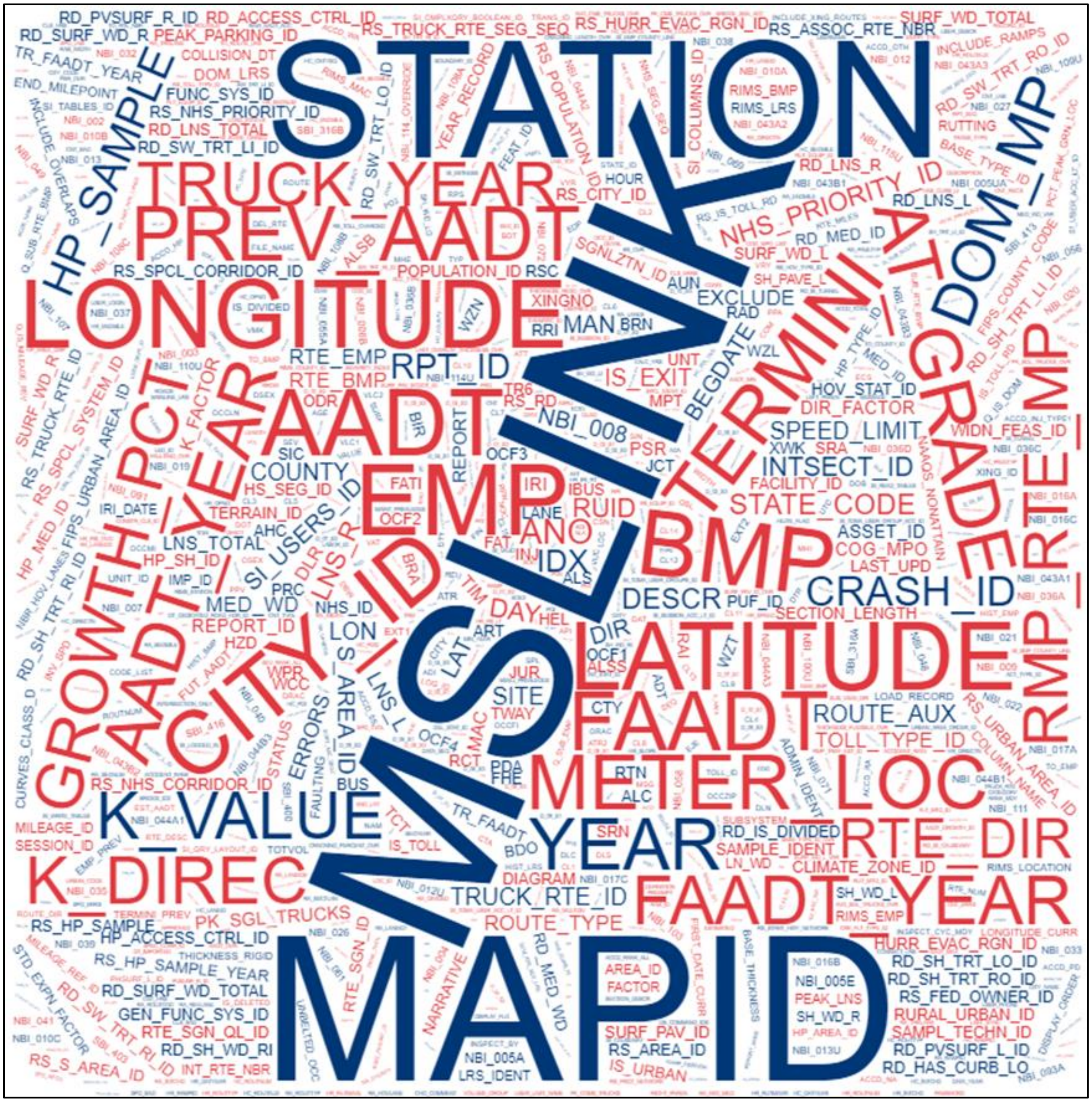


Figure 4.9 ITMS Data Dump Summary of Field Headers - Word Art Version 3
(Filtered Updated On and By Headers, min weight = 2)

4.1.2.2 Data Specification Tool

As received, the SCDOT asset database files were not easily evaluated. There were few domain translations available and uncertainty regarding data attributes (e.g., type, data value ranges, and whether null values are allowed). Therefore, a tool was developed in the R statistical software package to extract much of the missing information and populate a data table. Table 4.1 is a snapshot of the data specification variables extracted for the element 'Median_ID' contained in the SCDOT Source 'RIMS' database. For each element, the column name is supplemented with a summary name that is more descriptive – in this case, median type. Median Type is an Integer variable, which does not allow nulls and has a domain coding system. The count of populated rows is 75,195 and values range from minimum of zero to a max value of eight. For elements such as median type where a domain exists, the code values are listed along with the text translations, the frequency of appearance in the data file for each code, and the respective percentage of total. Further, if the data element has a recommended MIRE domain code and translation it is listed alongside the SCDOT codes. For median type, note that SCDOT maintains a category of 'Multilane – Bituminous Median' which overlaps two categories from the suggested MIRE domain, 'Flush Paved Median (at least 4 ft in width)' and 'Two-Way Left-Turn Lane (TWLTL)'. The MIRE domain is more descriptive and in terms of safety analysis allows analysts to distinguish between a flush painted or striped median and a road with a TWLTL. Highway Safety Manual classifications for these could be multilane undivided or multilane with TWLTL. On a recent Highway Safety Manual calibration research project, the research team had to use Google Maps to manually determine the bituminous median roadway category for analysis. The percent of total is a handy indicator of the magnitude of a certain type of feature in the state. For instance, there are very few one-way streets in South Carolina (at least in the RIMS data for state-maintained roadways).

Table 4.1 Example of Data Specification Tool Output

Column Name	Summary	Details	SCDOT Source	Data Type	Allow Nulls	Has Domain	Count of Values	Min	Max
Median_ID	Median Type		RIMS	Integer	NO	YES	75195	0	8

Domain

Code Value	Translation	Details	Freq	% of total	MIRE Domain Codes and Translation
0	Non-divided		65,946	87.68	1. Undivided 2. Flush paved median (at least 4 ft in width) 3. Raised median 4. Depressed median 5. Two-way left-turn lane 6. Railroad or rapid transit 7. Divided, separate grades without retaining wall 8. Divided, separate grades with retaining wall 9. Other divided
1	Divided - Earth Median		2,139	2.84	
2	Divided - Concrete Median		357	0.47	
3	Multi-lane - Bitum Median		6,008	7.99	
4	Divided - Raised Concrete & Surfaced Median		69	0.09	
5	Divided - Physical Barrier		264	0.35	
6	Divided - Cable Stay Guardrail		369	0.49	
8	One-way street		43	0.05	

This tool was used to develop the first draft of a data dictionary for several files that contained key elements for asset review (e.g., RIMS, AADT, and e-Teams). While these were helpful for the research team, they could be invaluable moving forward as resource within SCDOT. Very little effort would be required to verify the accuracy of the assumed descriptions, ranges, and domains. Once verified, these tables would provide a standard data dictionary for the asset files. This model and tool can also be adopted for other databases within the department. Having a good understanding of what is maintained in a data file increases the value and efficiency, as well as enables other users to have proficiency with the contents.

4.1.3 Performance Metrics Analysis

The focus for this analysis was placed on databases used to perform safety analysis. SCDOT has been compliant with reporting for HPMS and NBI for many years. However, with the ARNOLD legislation, MIRE FDE reporting requirements, and safety assessment requirements for ALL public roads, it seemed prudent to focus metrics analysis on the databases used for this purpose.

4.1.3.1 Data Requirements for Safety Data Systems

The MAP-21 legislation mandated that all states develop data driven safety analysis and evaluation programs for all roadways including local roads. The assessment requires integration of three fundamental sources (roadway, traffic, and crash data) for conducting safety analysis and evaluation. Figure 4.10 was taken from the FHWA Roadway Data Improvement Program Supplemental Guidance and shows that state safety data systems must include all public roads, a common base map, safety data (crash data, roadway data, and traffic data), analysis and evaluation, and all this feeding the Highway Safety Improvement Program.

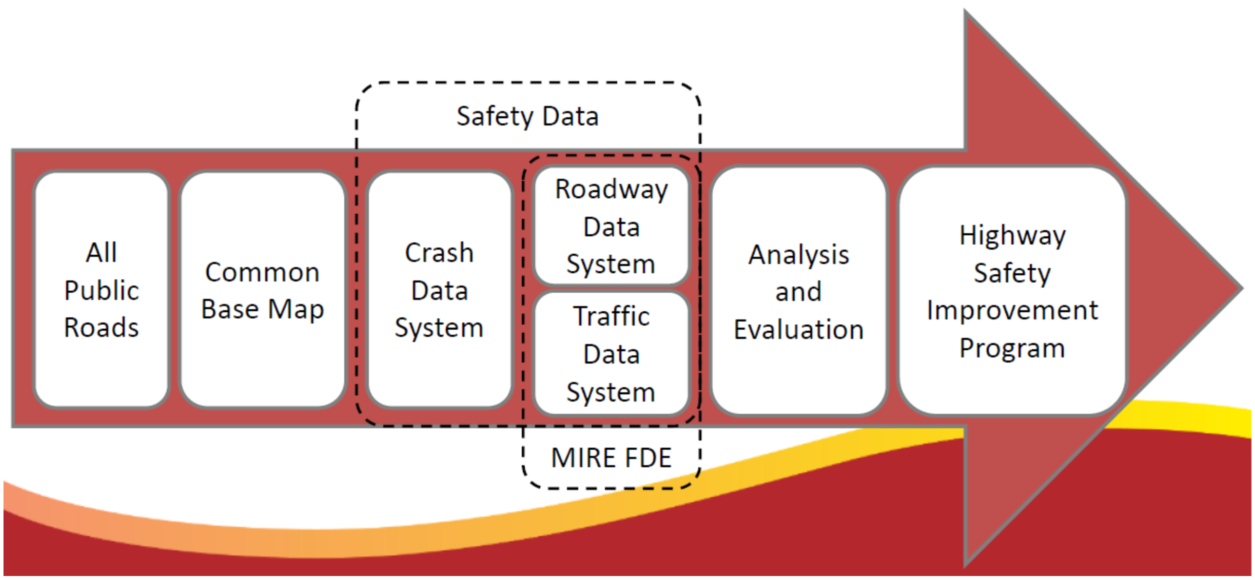


Figure 4.10 Components of State Safety Data System (Source: FHWA RDIP Supplemental Guidance)

Several resources have been developed to aid in the development of data driven safety analysis and evaluation programs. Figure 4.11 indicates guidance documents associated with each of the data components as well as tools developed for analysis and evaluation. Subsets of three of these resources are mandated by federal agenesis including MIRE Fundamental Data Elements, HPMS Required for Full Extent and Sample, and MMUCC Required. These required data are considered priority for any future SCDOT database development to satisfy federal reporting. For safety analysis, SCDOT has begun implementation of the Highway Safety Manual as the predominant tool for safety analysis, and significant research has already been conducted to develop statewide calibration factors. While HSM variables are not federally mandated, there are numerous variables that are used at the most basic levels to categorize route segments and intersections for HSM analysis and these are also considered priority. Without these elements, it is not possible to utilize the previously developed safety performance functions on a statewide scale. Table **4.2** provides a summary of the number of total and required elements from each of the mandated data programs and the state selected safety analysis tool – HSM. Note that the analysis provided here was conducted on MIRE 1.0 which listed 33 fundamental data element, whereas MIRE 2.0 contains 37 required data elements with varying detail based on the functional class of the roadway (see Table 4.3, Table 4.4, and Table 4.5). Given the prior research, much is already known about the data availability and conformity – this analysis confirmed existing experience.

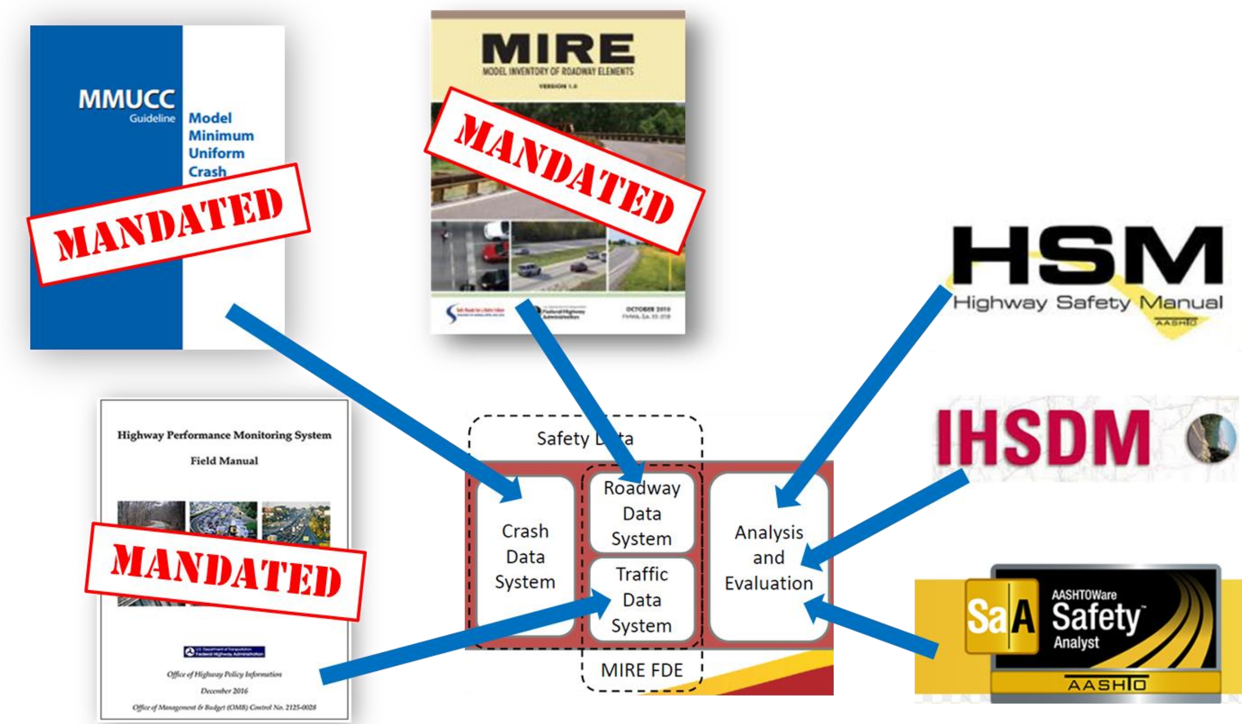


Figure 4.11 Required Inputs to Safety Data System

Table 4.2 Number of Elements for Federal Reporting/Safety Assessment Tools

Program/Tools	Total Number of Elements	Required Reporting Elements

Primary Elements (mandated)		
MIRE	202	33 FDE (MIRE 1.0) 37 FDE (MIRE 2.0)*
HPMS	47	27 FE, 20 S
MMUCC	110	110 R
Primary Elements (SC Specific HSM Models)		
HSM	124	90
Secondary Elements (MIRE not FDE, HSM required for predictive chapter use)		
HSM	124	27
MIRE	202	

* Note these elements groups did not exist until after the metric analysis had been completed.

Table 4.3 MIRE Fundamental Data Elements for Unpaved Roads

Roadway Segment
Segment Identifier (12)
Functional Class (19)
Type of Governmental Ownership (4)
Begin Point Segment Descriptor (10)
End Point Segment Descriptor (11)

Table 4.4 MIRE Fundamental Data Elements (MIRE 1.0 Element Number) for Local Paved Roads Based on Functional Classification

Roadway Segment
Segment Identifier (12)
Functional Class (19)
Surface Type (23)
Type of Governmental Ownership (4)
Number of Through Lanes (31)
Annual Average Daily Traffic (79)
Begin Point Segment Descriptor (10)
End Point Segment Descriptor (11)
Rural/Urban Designation (20)

Table 4.5 MIRE Fundamental Data Elements (MIRE 1.0 Element Number) for Non-Local Paved Roads Based on Functional Classification

Roadway Segment	Intersection	Interchange/Ramp
Segment Identifier (12)	Unique Junction Identifier (120)	Unique Interchange Identifier (178)
Route Number (8)	Location Identifier for Road 1 Crossing Point (122)	Location Identifier for Roadway at Beginning Ramp Terminal (197)
Route/street Name (9)	Location Identifier for Road 2 Crossing Point (123)	Location Identifier for Roadway at Ending Ramp Terminal (201)
Federal Aid/ Route Type (21)	Intersection/Junction Geometry (126)	Ramp Length (187)
Rural/Urban Designation (20)	Intersection/Junction Traffic Control (131)	Roadway Type at Beginning Ramp Terminal (195)
Surface Type (23)	AADT (79) [for Each Intersecting Road]	Roadway Type at Ending Ramp Terminal (199)
Begin Point Segment Descriptor (10)*	AADT Year (80) [for Each Intersecting Road]	Interchange Type (182)
End Point Segment Descriptor (11)*	Unique Approach Identifier (139)	Ramp AADT (191)
Segment Length (13)		Year of Ramp AADT (192)
Direction of Inventory (18)		Functional Class (19)
Functional Class (19)		Type of Governmental Ownership (4)
Median Type (54)		
Access Control (22)		
One/Two-Way Operations (91)		
Number of Through Lanes (31)		
AADT (79)		
AADT Year (80)		
Type of Governmental Ownership (4)		
Unique Junction Identifier (120)		
Location Identifier for Road 1 Crossing Point (122)		
Location Identifier for Road 2 Crossing Point (123)		
Intersection/Junction Geometry (126)		
Intersection/Junction Traffic Control (131)		
AADT (79) [for Each Intersecting Road]		
AADT Year (80) [for Each Intersecting Road]		
Unique Approach Identifier (139)		

4.1.3.2 Cross Reference Existing and Required Safety Data

Using the more extensive MIRE listing as the basis for an analysis master data sheet (sample shown in Table 4.6), the researchers extracted the fields of the MIRE as well as the database main structure. This broke the data into three main descriptor areas – roadway segments, roadway alignment, and roadway junction. An additional section contains required fields for HPMS and HSM that are not contained in the MIRE listing. Columns for data entry and analysis included:

- MIRE Fundamental – YES indicates that the element belongs to the list of MIRE 1.0 FDE
- Priority – This is a calculated field based on the Priority descriptions found in Table 4.2
- HPMS – Indicates if the element is required for Full Extent, Random Sample, or Both
- SafetyAnalyst – Indicates if the element is required or optional for SafetyAnalyst tool use
- HSM/IHSDM – Indicates if the element is required or optional for HSM/IHSDM tool use
- Based on Calibration Project – This column is multipart
    - HSM Required – Indicates if the element is required based on state-specific SPF model development for South Carolina. Required data are used in the classification, crash assignment, and state-specific SPFs. Level 2 (secondary data) are required for use of HSM prediction methods. Because Interstate facilities are critical, all data used for the predictions in CH 18-19 are required.
    - Facility Type – This indicates what facility types the element is required for including ALL facility types, CH10 (Rural 2-lane), CH11 (Rural Multilane), CH12 (Urban and Suburban 2-lane and multilane), and CH18 (Interstates)
    - Data Usage – This indicates what function within the HSM the data element is used. The functions include: 1) Classification – sorting the segments and intersections into respective classifications by area type, number of lanes, median, or traffic control; 2) Crash Assignment – needed to sort the crashes and assign to intersection or segment; and 3) CMF – the CMFs which were statistically significant in the state-specific models are shown here.
- SCDOT – This column is multipart
    - Inventory – This column indicates whether the data is collected by SCDOT and from which database it can be obtained
    - State – Y indicates the data element is collected for all state routes, N indicates it is not
    - Local – Y indicates the data element is collected for all state routes, N indicates it is not (**Note that local road data collection is predominantly limited to HPMS Sample sections)
- Comment – This field is used to note any particularly important pieces of information used by the researchers in analysis, such as indicating the fact that South Carolina Currently has no HOV lanes.

The complete database can be found in the electronic appendix – Appendix B Color Coded Master Sheet.

Table 4.6 Sample of Color-Coded Master Sheet showing Segment Descriptors

Code	Attributes	MIRE Fundamental	MIRE Priority	HPMS	Based on Calibration Project HSM RQRD	Based on Calibration Project Facility Type	Based on Calibration Project Data Usage	SCDOT State	SCDOT Local	SCDOT Inventory
	Segment Location Linkage									
3	Bridge Numbers for Bridges in Segment		Critical (unless addressed ir					Y	Y	RIMS
	Horizontal Curve Data									
2	Curve Identifiers and Linkage Elements		Critical		R	CH10,18	CMF	N	N	
2	Curve Feature Type		Critical		R	CH10,18	CMF	N	N	
1	Horizontal Curve Degree or Radius		Critical	Sample*	R	CH10,18	CMF	Y	Y	RIMS
1	Horizontal Curve Length		Critical	Sample*	R	CH10,18	CMF	Y	Y	RIMS
4	Curve Superelevation		Critical		2	CH10	CMF	N	N	
4	Horizontal Transition/Spiral Curve Presence		Critical		2	CH10	CMF	N	N	
4	Horizontal Curve Intersection/Deflection Angle		l (only for Horizontal Angle					N	N	
4	Horizontal Curve Direction		Critical					N	N	
	Vertical Grade Data									
4	Grade Identifiers and Linkage Elements		Critical		2	CH10	CMF	N	N	
4	Vertical Alignment Feature Type		Critical		2	CH10	CMF	N	N	
1	Percent of Gradient		Critical	Sample*	2	CH10	CMF	Y	Y	RIMS
1	Grade Length		Critical	Sample*	2	CH10	CMF	Y	Y	RIMS
4	Vertical Curve Length		Critical		2	CH10	CMF	N	N	
	At-Grade Intersection/Junctions									
2	Unique Junction Identifier	Yes	Critical		R	All	Classification	N	N	
1	Type of Intersection/Junction		Critical		R	All	Classification	Y	Y	RIMS
1	Location Identifier for Road 1 Crossing Point	Yes	Critical		R	All	Classification	Y	Y	RIMS
1	Location Identifier for Road 2 Crossing Point	Yes	Critical		R	All	Classification	Y	Y	RIMS
1	Location Identifier for Additional Road Crossing Points		Critical		R	All	Classification	Y	Y	RIMS
2	Intersection/Junction Number of Legs		Critical		R	All	Classification	N	N	
1	Intersection/Junction Geometry	Yes	Critical		R	All	Classification	Y	Y	RIMS
4	School Zone Indicator		Critical		O	CH12	CMF	N	N	
3	Railroad Crossing Number		Critical					Y	Y	RIMS
3	Intersecting Angle		Critical		2	CH10,11	CMF	Y	Y	RIMS
2	Intersection/Junction Offset Distance		Critical		R	All	Classification	N	N	
2	Intersection/Junction Traffic Control	Yes	Critical		R	All	Classification	N	N	
2	Signalization Presence/Type		Value added		R	All	Classification	N	N	
2	Intersection/Junction Lighting		Critical		R	All	State SPF	N	N	
4	Circular Intersection Number of Circulatory Lanes		Critical					N	N	
4	Circular Intersection Circulatory Lane Width		Value added					N	N	
4	Circular Intersection Inscribed Diameter		Critical					N	N	
4	Circular Intersection Bicycle Facility		Value added					N	N	
	Approach Descriptors (Each Approach)									
2	Intersection Identifier for this Approach		Critical		R	All	Classification	N	N	
2	Unique Approach Identifier	Yes	Critical		R	All	Classification	N	N	
2	Approach AADT		Critical		R	All	State SPF	N	N	

Table 4.7 Master Sheet Color Coding Index

Color Codes	Priority	Availability	Description
1	Primary	Collected	HPMS Full Extent, MIRE FE, SC Specific HSM Required
2	Primary	**Not** Collected	HPMS Full Extent, MIRE FE, SC Specific HSM Required
3	Secondary	Collected	Optional HPMS, MIRE, HSM Predictive Chapter Use
4	Secondary	**Not** Collected	Optional HPMS, MIRE, HSM Predictive Chapter Use

Upon completing the master sheet, comparisons between the MIRE guidance and mandatory MIRE FDE elements and SCDOT databases were analyzed. Table 4.8 provides the total number of MIRE 1.0 elements in each subcategory. On the right side of the table, two columns represent the number/percent of MIRE elements that are included in various SCDOT databases, as well as the number/percent that are not. The following points summarize the results of the MIRE vs SCDOT data analysis:

1. SCDOT databases contain only about 40% of the total MIRE 1.0 list of elements.
2. SCDOT databases contain a fair amount of roadway segment descriptors and lack most alignment and junction descriptors.
3. Segment location/linkage variables are well populated, and this can be attributed to a strong LRS policy.
4. The segment traffic and cross-section elements are the next two most populated categories with 75% and 46% represented in SCDOT data.
5. Little information is available for traffic control, alignment data, and intersections.
6. None of the included databases contained information on traffic characteristics like directional distributions, K-factors, and percent trucks in the traffic flow subcategory. For traffic operations/controls subcategory, nearly all databases lack information about speed limits, 85th percentiles speed, school zones indicators, and on street parking presence.
7. South Carolina does not currently have any HOV lanes, so these items were removed before analysis.

Table 4.8 Total number of MIRE 1.0 data elements maintained in SCDOT data inventories

MIRE Data Subcategories	Total MIRE 1.0 elements in subcategory	Elements for MIRE in SCDOT Databases by Category		Elements for MIRE Not in SCDOT Databases by Category	
		#	%	#	%
I. ROADWAY SEGMENT DESCRIPTORS (Total number of MIRE Elements = 106)					
I.a. Segment location/linkage var.	18	15	83.33	3	16.67
I.b. Segment roadway classification	4	4	100.00	0	0.00
I.c. Segment cross-section	39	18	46.15	21	53.85
I.d. Segment roadside descriptors	13	0	0.00	13	100.00
I.e. Other segment descriptors	4	4	100.00	0	0.00
I.f. Segment traffic flow data	12	9	75.00	3	25.00
I.g. Segment traffic ops/control data	15	4	26.67	11	73.33
I.h. Other supplemental descriptors	1	1	100.00	0	0.00
II. ROADWAY ALIGNMENT DESCRIPTORS (Total number of MIRE Elements = 13)					
I.a. Horizontal curve data	8	2	25	6	75
I.b. Vertical grade data	5	2	40	3	60
III. ROADWAY JUNCTION DESCRIPTORS (Total number of MIRE Elements = 83)					
III.a. At-Grade intersection/junctions	58	7	12.0690	51	87.931
III.b. Interchange and ramp descr.	25	14	56	11	44
Total Number of Elements	202	80	39.60	122	60.40

Similar analyses were conducted for MIRE FDE, HPMS, and HSM data elements. Table 4.9 summarizes the MIRE FDE data elements and their inclusion in SCDOT data inventories. Recall that MIRE 1.0 FDE is a 33-element subset of the 202 total MIRE elements. Overall, SCDOT databases contain about 88% of the MIRE FDE data elements. All the elements of roadway segment descriptors such as Segment location/linkage variables and Segment roadway classification are available in the SCDOT data inventories. However, SCDOT maintains only 50% of the MIRE FDE on roadway junctions, which include interchanges, intersections, and ramps. The uncollected MIRE 1.0 FDE data attributes contain information about identifiers, Ramp length, traffic data, Road types at the beginning and end of Ramp terminals. Most of these elements are required for safety analysis according the HSM data list. With the implementation of HPMS ARNOLD, SCDOT should be well positioned to add this data in the future.

Table 4.9 Total number of MIRE 1.0 FDE data elements maintained in SCDOT data inventories

MIRE Data Subcategories	Total MIRE 1.0 FDE elements in subcategory	Elements for MIRE FDE in SCDOT Databases by Category		Elements for MIRE FDE Not in SCDOT Databases by Category	
		#	%	#	%
I. ROADWAY SEGMENT DESCRIPTORS (Total number of MIRE Elements = 106)					
I.a. Segment location/linkage variables	8	8	100	0	0
I.b. Segment roadway classification	4	4	100	0	0
I.c. Segment cross-section	3	3	100	0	0
I.d. Segment roadside descriptors	--	--	--	--	--
I.e. Other segment descriptors	--	--	--	--	--
I.f. Segment traffic flow data	2	2	100	0	0
I.g. Segment traffic ops/control data	1	1	100	0	0
I.h. Other supplemental descriptors	--	--	--	--	--
II. ROADWAY ALIGNMENT DESCRIPTORS (Total number of MIRE Elements = 13)					
I.a. Horizontal curve data	--	--	--	--	--
I.b. Vertical grade data	--	--	--	--	--
III. ROADWAY JUNCTION DESCRIPTORS (Total number of MIRE Elements = 83)					
III.a. At-Grade intersection/junctions	6	3	50	3	50
III.b. Interchange and ramp descriptors	9	8	88.89	1	11.11
Total Number of Elements	33	29	87.88	4	12.12

Table 4.10 lists the MIRE Version 1.0 data elements required by the HPMS program and found in the SCDOT data inventories. The research team observed that the SCDOT databases contain about 92.59% (25 of 27) of the HPMS Full Extent elements. Of the 5 HPMS FE data items for Segment cross-section, only 2 data items were not collected including High Occupancy Vehicles (HOV) Lane Presence/Type, and HOV Lanes. Given that SCDOT does not have any of these facilities, all (100%) HPMS elements in the MIRE list are collected and The HPMS Sample dataset contains 20 data items of 20 in the MIRE 1.0. This is not surprising given that the HPMS is one of the older mandated databases. HPMS significantly contributes to the fulfillment of MIRE FDE compliance.

Table 4.10 Total Number of MIRE 1.0 elements required by HPMS maintained in SCDOT data inventories

MIRE Data Subcategories	Total HPMS elements in a subcategory		Elements for HPMS in SCDOT Databases by Category				Elements for HPMS NOT in SCDOT Databases by Category			
			FE		Sample		FE		Sample	
	FE	S	#	%	#	%	#	%	#	%
I. ROADWAY SEGMENT DESCRIPTORS (Total number of MIRE Elements = 106)										
I.a. Segment location/linkage variables	11	--	11	100	---	---	0	100	---	----
I.b. Segment roadway classification	4	--	4	100	---	---	0	100	---	---
I.c. Segment cross-section	5	10	3	60	10	100	2	40	0	0
I.d. Segment roadside descriptors	---	---	---	---	---	----	----	---	---	----
I.e. Other segment descriptors	---	4	----	---	4	100	---	---	0	0
1.f. Segment traffic flow data	5	2	5	100	2	100	0	0	0	0
I.g. Segment traffic ops/control data	2	2	2	100	2	100	0	0	0	0
I.h. Other supplemental descriptors	---	---	---	----	---	---	---	---	---	----
II. ROADWAY ALIGNMENT DESCRIPTORS (Total number of MIRE Elements = 13)										
II.a. Horizontal curve data	---	1	---	----	1	100	---	---	0	0
II.b. Vertical grade data	----	1	---	----	1	100	---	---	0	0
III. ROADWAY JUNCTION DESCRIPTORS (Total number of MIRE Elements = 83)										
III.a. At-Grade intersection/junctions	---	---	---	---	---	---	---	---	---	---
III.b. Interchange and ramp descr	---	---	---	---	---	---	---	---	---	---
Total Number of Elements	27	20	25	92.59	20	100	2	7.41	0	0

* FE= full extent, S= sample, #= number, and %=percentage.

Table 4.11 reports on the status of SCDOT databases to support MIRE data elements contained in the Highway Safety Model (HSM). The results of this analysis indicate that the SCDOT data inventories seem to have the least number of HSM Required (for Classification and Stateside SPF usage) and HSM Optional data elements with 42.74% and 0%, respectively. Available data elements focus predominantly on segment identification and classification; whereas, cross-section, roadside, traffic control, alignment and intersections had numerous missing elements. This is consistent with what was experienced on the SCDOT HSM Calibration project completed last year. Missing data, including the presence of a two-way left-turn lane, precluded the research team from classifying all segments prior to data collection. This required significantly more samples to be obtained, reviewed, and manually classified before the actual research could begin.

Table 4.11 Number of Required and Optional HSM data elements in MIRE Version 1.0 maintained in SCDOT data inventories

MIRE Data Subcategories	Total HSM elements in a subcategory		HSM elements in SCDOT Databases by Category				HSM elements NOT in SCDOT Databases by Category			
			Required		Optional		Required		Optional	
	R	O	#	%	#	%	#	%	#	%
I. ROADWAY SEGMENT DESCRIPTORS (Total number of MIRE Elements = 106)										
I.a. Segment location/linkage var	7	---	7	100	--	--	0	0	--	--
I.b. Segment roadway classification	2	---	2	100	--	--	0	0	--	--
I.c. Segment cross-section	24	---	10	41.67	--	--	14	58.33	--	--
I.d. Segment roadside descriptors	11	---	0	0	--	--	11	100	--	--
I.e. Other segment descriptors	--	---	--	--	--	--	--	--	--	--
1.f. Segment traffic flow data	3	2	3	100	0	0	0	0	2	100
I.g. Segment traffic ops/control data	8	1	4	50	1	0	4	50	0	0
I.h. Other supplemental descriptors	-----	----	---	---	----	----	----	---	---	---
II. ROADWAY ALIGNMENT DESCRIPTORS (Total number of MIRE Elements = 13)										
II.a. Horizontal curve data	6	--	2	33.33	--	--	4	66.67	--	--
II.b. Vertical grade data	5	--	2	40	--	--	3	60	--	--
III. ROADWAY JUNCTION DESCRIPTORS (Total number of MIRE Elements = 83)										
III.a. At-Grade intersection/junctions	28	4	6	21.43	0	0	22	78.57	4	100
III.b. Interchange and ramp descr	23	--	14	60.87	--	--	9	39.13	--	--
Total Number of Elements	117	7	50	42.74	1	0	67	57.26	6	85.71

* R= required, O= optional, #= number, and %=percentage

To summarize what was found when comparing Model Inventory of Roadway Elements to the elements maintained by SCDOT, only about 40% of the total MIRE list was met.

SCDOT databases are fairly complete for:

- *Roadway segment descriptors*
- *Segment location/linkage variables*
- *Segment cross-section*

SCDOT databases tend to lack:

- *Alignment and junction descriptors*
- *Segment traffic flow data and operations*
- *Traffic Control data*
- *Directional and K-factors*
- *Percent trucks in the traffic flow subcategory.*
- *Traffic Operation/controls,*

- *Speed limits,*
- *85th percentiles speed,*
- *School zones indicators, and*
- *On street parking presence.*

While there may be other SCDOT databases that contain these elements, they were not easily identified from the ITMS data tables. This may indicate that the SCDOT lacks critical roadway and traffic inventory data necessary for highway safety management, or it is suggestive of the lack of proper meta data and data dictionaries that would normally be accessed during such as task. The gaps will be revisited along with a discussion of advantages of new technologies for advancing data collection. One final note of concern relates to the fact that safety programs should consider ALL public roads (MAP-21 requirements), but most of the collected data reported in the tables above only represent the highest volume classifications of roadways (e.g., HPMS collected for samples of only National-Aid Roadways).

4.1.3.3 Cross Reference Existing Crash and MMUCC Requirements

While crash data is collected by the South Carolina Department of Public Safety (SCDPS), it is a key data element in safety analysis and crash files are maintained by SCDOT. A secondary cross-referenced analysis was conducted on SCDPS provided crash data and the Minimum Model of Uniform Crash Criteria. The MMUCC data elements available in multiple tables including crash location, units involved in the crash, and vehicle occupancy were reviewed in Table 4.12.

The table shows that the crash database contains only 65% (71 of 110 MMUCC) of the mandated elements for 2015. The available data elements were mostly related to crash and vehicle data which are both collected on the scene by the law enforcement officers. It is understandable that the occupant information was also lacking because these data are private and require additional security to maintain. However, MMUCC has expectations for data to be obtained from the roadway network and included in a complete table. SCDOT can merge and add the data, but this is not contained directly in the resident file. This is not considered a negative aspect, as data redundancy can be problematic. However, the key question is whether the crash data are easily integrated within the ITMS environment to allow the roadway data to be fully analyzed alongside the crash data.

Table 4.12 the number of the SCDOT data elements collected from three data bases in 2015 classified based on different subcategory.

MMUCC Attributes	Total Elements in each subcategory	Location	Occupancy	Units
Data Elements Collected at the Scene				
I Crash Data Elements	19	16	0	2
II Vehicle Data Elements	30	5	2	18
III Person Data Elements				3
III.A Level 1: All Persons Involved	5	0	1	
III.B Level 2: All Occupants	5	0	4	1
III.C Level 3: All Drivers	6	1	0	4
III.D Level 4: All Drivers and Non-motorists	5	0	0	1
III.E Level 5: Non-Motorists (includes peds)	7	0	2	1
III.F Level 6: All Injured	1	0	1	0
IIII Derived and Linked Data Elements	9	1	0	2
IIIII Person Data Elements Derived	1	0	1	0
Person Data Elements Obtained After Linkage to Other Data				
Level 3. All Drivers	3	0	0	2
Level 6. All Injured Persons	3	0	2	1
Roadway Data Elements Obtained After Linkage to Other Data				
RL1. Bridge/Structure Identification Number	16	2	0	1

4.1.3.4 Data Quality Metric Analysis

The assessment of quality of the SCDOT databases is an important step to improve the current roadway safety data capabilities. The quality metrics (accuracy, completeness, and uniformity) were evaluated for the SCDOT roadway, traffic, and crash data elements to support mandatory requirements (MIRE FDE and HPMS FE), as well as the HSM R data requirements to support full implementation of the Highway Safety Manual. As shown in Table 4.13, six quality measures were selected for this analysis including one accuracy metric, four completeness metrics, and one uniformity metric. The three-character codes will be used in the following figures to indicate the various metrics for each respective database to be assessed. For instance, R-A-1 indicates **R**oadway Database – **A**ccuracy Quality – Metric **1**.

Table 4.13 Selected Quality Measures

<table>
<tr><th>Roadway Database Accuracy</th><th>Roadway Database Completeness</th><th>Roadway Database Uniformity</th></tr>
<tr><td rowspan="4">R-A-1: The percentage of all road segment records with no errors in critical data elements.</td><td>R-C-1: The Percentage of roads with no missing critical data elements.</td><td rowspan="4">R-U-1: The number of MIRE compliant data elements entered to the database or obtained via linkage to other data bases.</td></tr>
<tr><td>R-C-2: The percentage of public road miles or jurisdictions identified on the State's base map or roadway inventory file.</td></tr>
<tr><td>R-C-3: The percentage of unknowns or blanks in critical data elements for which unknown is not an acceptable value.</td></tr>
<tr><td>R-C-4: The percentage of total roadway segments that include location coordinates, using measurement frames such as a GIS base map.</td></tr>
</table>

The following performance measures, proposed by the National Highway Traffic Safety Administration (NHTSA) for roadway data accuracy, are used to evaluate the performance of the SCDOT databases.

- Accuracy reflects the number of errors in information entered the data inventory. The Errors are incorrectly recorded values in each data element as compared to the domain codes and does not include errors of omission. Some examples of deducing errors in the records include: lacking a legitimate code, codes not matching an external source of information, and having duplicate records for the same event.
- Completeness measures both internal and external aspects for the database being evaluated. The external component reflects the portion of the applicable events in the state for which the data is collected and entered the database. This aspect is more challenging because of the problems related roadway ownership (state vs local), as well as funding designations. Whereas, the internal aspect measures whether the databases contain precise information (i.e., the number of missing records (null/blank) for each data element).
- Uniformity reflects the consistency of the files and records in the databases as measured against some independent standards (i.e., coding consistency with MIRE for roadways and traffic, and MMUCC for crash databases).

While NHTSA provided numerous examples of metrics, the metrics chosen for this research were ones that the research team deemed usable given the information that was available. The output from the data specification tool provided information for individual elements that was critical input for this task because it set forth the ranges, coding structures, and distribution of codes against which measurements can be made. The data subcategories (i.e., segment location linkage or horizontal alignment data) contain multiple data elements, so a combined scored was obtained for each subcategory. Each element in the subcategory received a point score representing the quality range using the four-point element level scale described in Table 4.14. With each element scored, a weighted average composite score was calculated across all elements within the subcategory. The point scores allowed the analysis to provide to normalized scores across the range of elements and subcategories. Scores range from 0 to 4, and 4 is considered the best score. While these metrics are not perfect and rely on some assumptions, they do reflect the issues observed by the research team on prior research projects.

Table 4.14 Weighted point system for each element based on maturity level of data

Description	Point Value	Percentage
Poor	1	0-40
Fair	2	41-60
Good	3	61-80
Very Good	4	81-100

The quality metrics were used to evaluate the critical SCDOT roadway and traffic data elements for roadway safety analysis (i.e., MIRE FDE, HPMS FE, and HSM R). The results are presented in Figure 4.12, Figure 4.13, Figure 4.14. In general, completeness had the lowest scores of the quality attributes measured, and traffic control and roadside data element categories consistently scored low. For most databases, the segment location linkage had the highest performance in terms of number of data elements and quality of collected data. Again, this points to a strong linear referencing system. While the HPMS has relatively good representation in MIRE, the limited scope of the HPMS database with regard to all public road coverage lowers the scores. In general, data groupings not found in HPMS (such as traffic control and roadsides) scored lower. So, while HPMS is a mature database, it does not fulfill all data requirements equally.

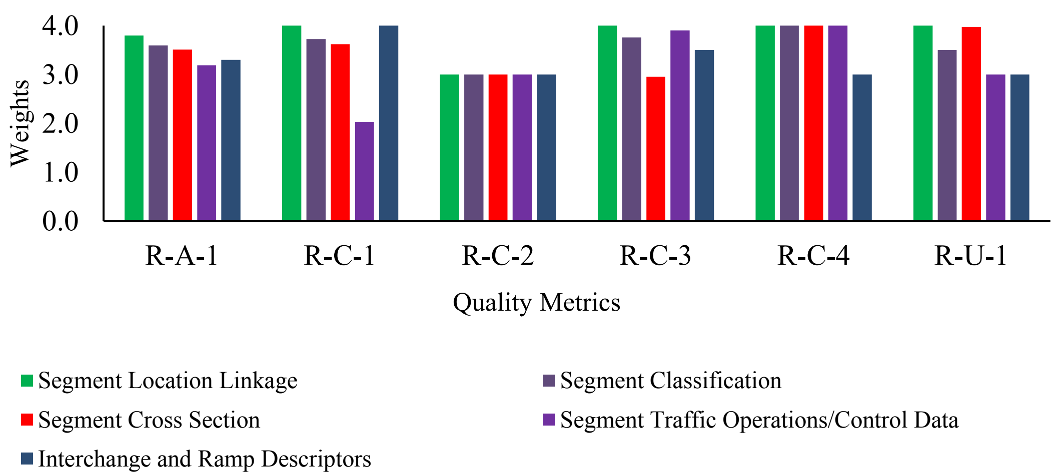


Figure 4.12 Data quality metric estimates for SCDOT databases with respect to MIRE FDE

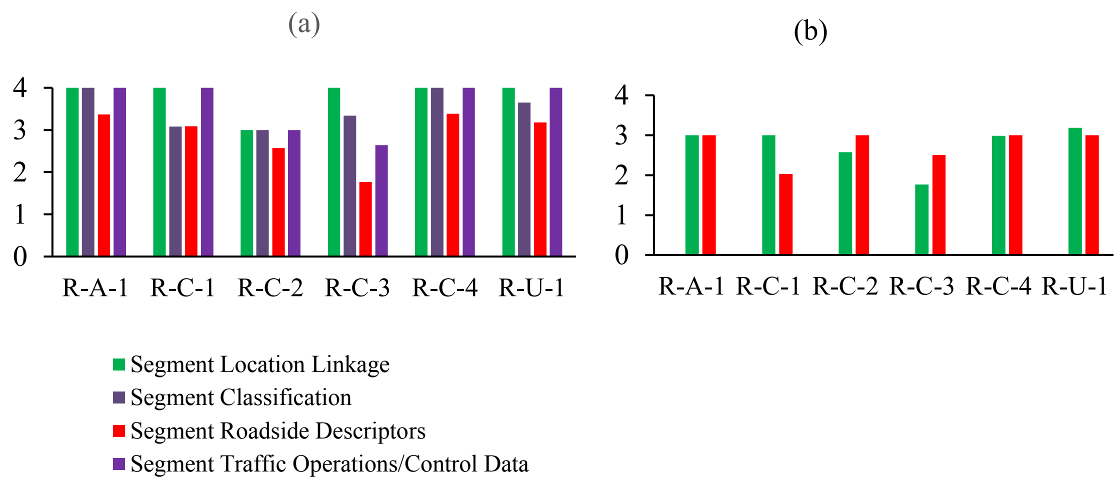


Figure 4.13 Data quality metric estimates for SCDOT databases with respect to (a) HPMS FE, and (b) HPMS Sample.

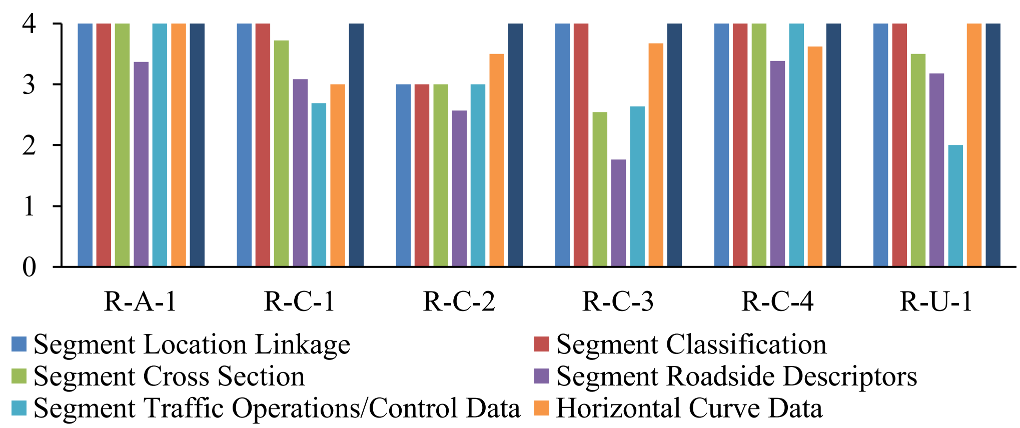


Figure 4.14 Data quality metric estimates for SCDOT databases with respect to HSM

A similar process was followed to estimate data quality measures for crash data elements compared to MMUCC's crash requirements. When evaluating crash data, it was discovered that a considerable percentage of crash attributes can accept blanks as a typical entry to indicate the lack of involvement of that element in the event. Table 4.15 gives a sample showing that (e.g., Number of Trucks or Buses involved in accidents, Relation to Junction, and Type of Intersection), signed as "Allow Nulls" in the comprehensive summary list shown in Appendix B. Therefore, the performance measures for fields with such criteria were overlooked in this process. The result outputs in this step were grouped into three categories including the fields of location of the crash, units involved in the accident, and the number of occupants related data elements.

Table 4.15 An example of a valid blank entries in case of crash data.

TableName	Field Name	Translation	Description	Min Value	Max Value	Count of Values	Data Type	Allow Nulls	Has Domain
SC_Crash_201	ART	Ramp-Type	This area is to be completed only if the collision occurs on a ramp	0	1	2570	Integer	Yes	Yes
	Codes	Frequency	Code Definitions	% Of Competion					
		144453		98.252					
	0	716		0.487					
	1	1854	Entrance	1.261					
SC_Crash_201	HZD	Number of Hazardous Vehicles		1	2	84	integer	Yes	Yes
	Codes	Frequency	Code Definitions	% Of Competion					
		146939		99.943					
	1	82		0.056					
	2	2		0.001					
SC_Crash_201	BUS	# of Buses		1	2	273	integer	Yes	Yes
	Codes	Frequency	Code Definitions	% Of Competion					
		146750		99.814					
	1	269		0.183					
	2	4		0.003					

The weighted performance measures for the three components of crash data, Location, Unit, Occupants, are presented in Figure 4.15. As seen in this table, the evaluated crash variables showed good data quality as all performance was >3.0. However, the percentage of the evaluated variables is only 55% of the total data elements in the three databases focusing on some variables such as spatial location of crash and linear referencing, system, route name and type, and traffic conditions. The Location and Units databases show higher performance, while the Occupant table shows lower performance because it lacked some elements and contained various coding errors in fields such as driver name (redacted), gender, seat location, and ejection status. For the other 45% percentage of the data, the team found that there were about 10 unused variables for unknown reasons. For example, investigating agency, traffic control type, driver license class and others did not contain any information.

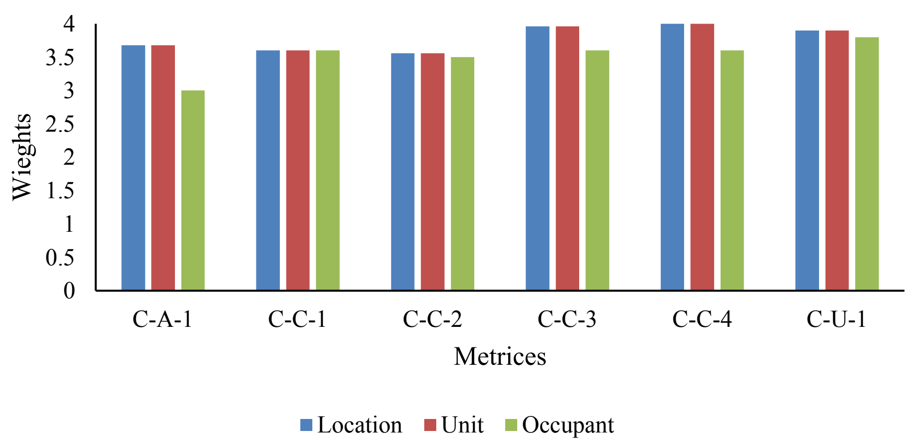


Figure 4.15 An overall performance measures weighting for crash inventories in 2015.

Under MAP-21, the SCDOT should establish statewide performance measures for all program areas. Given that most of the data in the inventories are closely related to the HPMS program data coverage (i.e., Federal Aid Highways), this means that many of these variables are either not currently collected for lower level roads or collected only for small samples. Finally, the recommendation for developing performance measures is expected to expand to include all roadways systems and for additional assets (e.g., intersection traffic control, interstate pavement, and bridges).

4.2 Database Gap Analysis and Data Collection Technologies

The second phase of research assessed potential data collection technologies for comprehensive asset data inventory to fulfill gaps in existing data. Given that the existing data was obtained 30 years ago and has not be resurveyed, this is a prime time to consider new data collection technologies and all the added benefits associated with LiDAR point cloud data. There are four distinct sections: 1) gap analysis, 2) vendor rodeo setup, 3) vendor rodeo assessment, and 4) state-of-the-art model review.

4.2.1 Gap Analysis

After the safety data sources had been compiled and analyzed, the research continued with a gap analysis. The master sheet was used to determine which MIRE elements were missing. A separate database (shown in Table 4.16) aids in identifying attributes that can be obtained via LiDAR as collected for UDOT using state-of-the-art comprehensive mobile data collection technology. The table also indicates whether the data element has been collected either in an automated or semi-automated way using LiDAR. The last column in the table describes the difficulty level of collecting the data manually, if members of the research team had done so in the past.

Table 4.16 Missing Attributes and Data Collection Technology Assessment

Attributes	UDOT LiDAR Y-N/ Inventory Names/ Collection Method	Difficulty Rating for Manual Data Collection Using Imagery
Segment Cross Section (Cont.)		
Width of Bicycle Facility	Yes/Bike Lanse/Auto	NA
Number of Peak Period Through Lanes	yes/UDOT HPMS Samples2014	NA
Right Shoulder Type	Yes/Shoulders/Auto	2
Right Shoulder Total Width	Yes/Shoulders/Auto	3
Right Paved Shoulder Width	Yes/Shouler/Auto	NA
Right Shoulder Rumble Strip Presence/Type	Yes/Rumblestrips/Auto	2
Left Shoulder Type	Yes/Shoulders/Auto	3
Left Shoulder Total Width	Yes/Shoulders/Auto	NA
Left Paved Shoulder Width	Yes/Shoulders/Auto	NA
Left Shoulder Rumble Strip Presence/Type	Yes/Rumblestrips/Auto	NA
Sidewalk Presence	Yes/Driveways(2014)/Auto	NA
Curb Presence	Yes/Pavem Sect Data-Current	NA
Curb Type	Yes/Pavem Sect Data-Current	NA
Median Type	Yes/Medians(2014)/Auto	3
Median Width	Yes/Medians(2014)/Auto	2
Median Barrier Presence/Type	Yes/Barriers(2014)/ Auto	3
Median (Inner) Paved Shoulder Width	Yes/Medians(2014)/Auto	NA
Median Shoulder Rumble Strip Presence/Type	Yes/Rumblestrips/Auto	NA
Median Sideslope	NA	NA
Median Sideslope Width	NA	NA
Median Crossover/Left Turn Lane Type	NA	NA

The gap analysis of MIRE data elements not-contained in SCDOT databases was compiled from the master list. For each element, notes were made to indicate if each element was a first priority element (indicated with data requirement in parentheses). Table 4.17provides a sample of these elements for various sections of data. The entire master sheet is provided in Appendix (A).

Table 4.17 MIRE Version 1.0 data gaps in SCDOT inventories

Segment Location Linkage	**At-Grade Intersection/Junctions**
Specific Governmental Ownership	Unique Junction Identifier
City/Local Jurisdiction Urban Code	Intersection/Junction Number of Legs
Coinciding Route — Minor Route Information	School Zone Indicator
Segment Cross Section	Intersection/Junction Offset Distance
Surface Friction	Intersection/Junction Traffic Control
Surface Friction Date	Signalization Presence/Type
Outside Through Lane Width	Intersection/Junction Lighting
Inside Through Lane Width	Circular Intersection Number of Circulatory Lanes
Cross Slope	Circular Intersection Circulatory Lane Width
Auxiliary Lane Presence/Type	Circular Intersection Inscribed Diameter
Auxiliary Lane Length	Circular Intersection Bicycle Facility
HOV Lane Presence/Types	**Approach Descriptors (Each Approach)**
HOV Lanes	Intersection Identifier for this Approach
Reversible Lanes	Unique Approach Identifier
Presence/Type of Bicycle Facility	Approach AADT/Year
Width of Bicycle Facility	Approach Directional Flow
Right Paved Shoulder Width	Number of Approach Through Lanes
Right Shoulder Rumble Strip Presence/Type	Left Turn Lane Type
Left Paved Shoulder Width	Number of Exclusive Left Turn Lanes
Left Shoulder Rumble Strip Presence/Type	Amount of Left Turn Lane Offset
Curb Type	Right Turn Channelization
Median Shoulder Rumble Strip Presence/Type	Traffic Control of Exclusive Right Turn Lanes
Median Sideslope	Number of Exclusive Right Turn Lanes
Median Sideslope Width	Length of Exclusive Turn Lanes
Median Crossover/Left Turn Lane Type	Median Type at Intersection
Segment Roadside Descriptors	Approach Traffic Control
Roadside Clearzone Width	Approach Left Turn Protection
Right Sideslope	Signal Progression
Right Sideslope Width	Crosswalk Presence/Type
Left Sideslope	Pedestrian Signalization Type
Left Sideslope Width	Pedestrian Signal Special Features
Roadside Rating	Crossing Pedestrian Count/Exposure
Driveway Counts/Classification	Left/Right Turn Prohibitions
Segment Traffic Flow Data	Right Turn-On-Red Prohibitions
AADT Annual Escalation Percentage	Left Turn Counts/Percent/Year
Total Daily Two-Way Pedestrian Count/Exposure	Right Turn Counts/Percent/Year
Bicycle Count/Exposure	Transverse Rumble Strip Presence
Segment Traffic Operations/Control Data	Circular Intersection Entry Width
Truck Speed Limit	Circular Intersection Number of Entry Lanes
Nighttime Speed Limit	Circular Intersection Presence/Type of Exclusive Right Turn Lane
85th Percentile Speed	Circular Intersection Entry Radius
Mean Speed	Circular Intersection Exit Width
School Zone Indicator	Circular Intersection Number of Exit Lanes
On-Street Parking Presence	Circular Intersection Exit Radius
Roadway Lighting	Circular Intersection Pedestrian Facility
Edgeline Presence/Width	Circular Intersection Crosswalk Location
Centerline Presence/Width	Circular Intersection Island Width
Centerline Rumble Strip Presence/Type	**Interchange and Ramp Descriptors**
Horizontal Curve Data	Interchange Type
Curve Identifiers and Linkage Elements	Interchange Lighting
Curve Feature Type	Interchange Entering Volume
Curve Superelevation	Interchange Identifier for this Ramp
Horizontal Transition/Spiral Curve Presence	Ramp Acceleration Lane Length
Horizontal Curve Intersection/Deflection Angle	Ramp Deceleration Lane Length
Horizontal Curve Direction	Ramp Metering
Vertical Grade Data	Ramp Advisory Speed Limit
Grade Identifiers and Linkage Elements	Roadway Feature at Beginning Ramp Terminal
Vertical Alignment Feature Type	Roadway Type at Ending Ramp Terminal
Vertical Curve Length	Roadway Feature at Ending Ramp Terminal

The data from Table 4.16 and Table 4.17 were merged to determine which elements SCDOT does not collect for MIRE FDE, and HPMS FE/S, HSM R, and MMUCC R. These are top priority elements. Table 4.18 shows the total number of elements as compared to the total number that has been collected in an automated or semi-automated fashion using mobile LiDAR data collection technologies. Finally, the number and level of difficulty was assessed for those variables that the team had ever collected by hand.

Table 4.18 Data Priority, Gaps, LiDAR Potential, and Manual Collection Difficulty Level

Database	# NOT collected By SCDOT	# Collected by Other States Using LiDAR	Difficulty of Manual Collection		
			Low	Medium	High
1st Priority gaps					
MIRE FDE	4	4	--	--	--
HPMS FE, S	2,0	0	--	--	--
HSM R	43	30	--	1	--
MMUCC R	--	--	--	--	--
2nd Priority gaps					
HSM O	6	0	--	--	--
MIRE Non-FDE	122	30	2	3	2

The review of critical and non-critical data elements from MIRE and SCDOT databases revealed that about 60% (122 of 202) of MIRE data elements were not collected by SCDOT (i.e., gaps). This included a few MIRE FDE, HPMS FE, and a considerable number of HSM R. The full list is provided in the Appendix C. SCDOT lacks more than 50% of the database elements required for HSM safety implementation on state roadways. These data elements contain information on Segment Cross Section, Segment Roadside Description, At Grade Intersection/Junctions, and Approach Descriptors (Each Approach). Based on the information provided in Table 4.18, **70% of the SCDOT gaps in first priority data can be collected using LiDAR technology.**

Summary of Safety Data Gaps:

- *The SCDOT databases have about 88% of the MIRE FDE data elements (excluding HOV because there were none in SC).*
- *60% (122 of 202) of total MIRE data elements were not collected by the SCDOT (considered gaps) including a few numbers of MIRE FDE, and a considerable number of HSM R.*
- *SCDOT data inventories have the least number of HSM data elements with 42.74% HSM R, and 0.00% HSM O data elements, respectively.*

- *MIRE Fundamental Data Elements follow HPMS reporting requirements closely. Unfortunately, the HPMS coverage is biased toward the higher functional classes and only sampled for lower classes. This leaves several gaps for lower functional class roadways.*
- *The SCDOT lacks more than 50% of the database elements required for HSM safety implementation in the state (e.g., Segment Cross Section, Segment Roadside Description, At Grade Intersection/Junctions).*
- *Data gaps for primary elements include MIRE and HSM variables related to traffic control, horizontal and vertical alignment. Ramps, ramp volumes, and intersection configuration were the most critical gaps in secondary elements.*

4.2.2 Vendor Rodeo Field Test Setup

This research evaluated the use of Mobile LiDAR Survey (MLS) from five vendors to obtain roadway design parameters and asset attribution. This was conducted in conjunction with a test of cross-slope verification. Three roadway test sections were used in performing the research; however, a four-lane parkway without any curb cuts (driveways) in Anderson, SC was the sole sight for asset attribution.

The study section was a three-mile corridor along East-West Parkway (EW Pkwy) in Anderson, SC shown in Figure 4.16. The study section originates at US-76 (Clemson Boulevard) and terminates at the SC-81 (E Greenville St). EW Pkwy is a limited access four-lane, two-way, mostly divided highway. It has a variety of geometric design elements including fifteen vertical curves, seven horizontal curves (all super elevated), one bridge, two intersections, traversable and non-traversable medians, two lanes per direction with an additional turning lane at intersections, and sections with adjacent bike lane and separate bike path (see Figure 4.17).

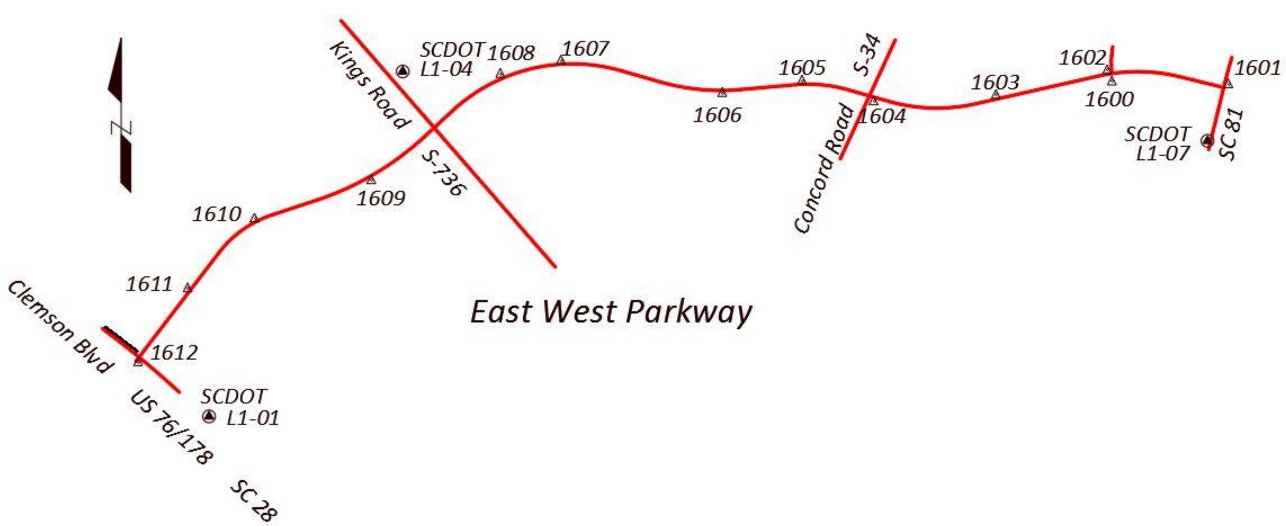


Figure 4.16 GCPs and check points along the three-mile study section

Figure 4.17 Sample photos from the MLS test corridor

MLS combines precise ranging, with high accuracy GPS and an integrated IMU to obtain a very dense point cloud (see Figure 4.18). The resulting point cloud can be useful for many applications such as asset data collection (e.g., lane widths and presence of median) or measuring bridge clearances but may not be accurate enough for surveying or some engineering applications such as calculation of geometric design features. To improve accuracy for this research, a ground control survey was conducted that identified primary and secondary geodetic control point (GCP) locations throughout the corridor. At least two primary GCPs were used by venders as base station locations for GPS differential correction and all the GCPs (both primary and secondary) were used for post-processing adjustment. Figure 4.16 shows the GCP locations along the study corridor.

Figure 4.18 Example of LiDAR point cloud and corresponding picture

The corridor was also surveyed to locate 100-ft. stations along white edge lines. These locations were marked with PK surveying nails. Eight of these locations were selected along the corridor as cross slope test sections. The test sections were selected to ensure diverse roadway cross slope characteristics including differing lane geometry, normal crown, and super elevated sections. PK surveying nails were also added to the yellow centerline markings. Reflective pavement marking tape was used to ensure that PK nail locations could be identified in the LiDAR data using the intensity attribute.

LiDAR data for the test section was collected by two vendors on June 30th, 2016 and two other vendors on August 30th, 2016. The section one vendors and their stated equipment specifications are provided in Table 4.19 **Vendor Data Collection Specifications for the Test Section**. Vendors could calibrate their systems both before and after data collection runs. A primary benefit of MLS is that point cloud data can be collected for multiple travel lanes with a single pass. For this study, vendors were asked to collect data by direction by driving in the right lane. Only a single pass was allowed for each direction. Vendors were asked to follow a lead vehicle that drove at the posted speed limit. For section one, traffic control was provided by two trailing SCDOT vehicles driving side by side so that no cars could pass the vendor data collection vehicles; however, for practical purposes, there was no traffic control for the opposing travel direction.

Table 4.19 Vendor Data Collection Specifications for the Test Section

Brand	Vendor A	Vendor B	Vendor C	Vendor D
	Riegl	Teledyne Optech	Teledyne Optech	Z+F Profiler
Model	VMX450	M1	SG1	9012
Single Laser or Dual	Dual	Dual	Dual	Single
Measurement rate	1100 kHz	500 kHz / sensor	600kHz (each Laser)	1000 kHz

4.2.3 Results from the Vendor Rodeo

The vendors provided several forms of data resulting from their data collection trials including:

- Dense point clouds
- Digital snapshot of sample photolog and corresponding laser data
- Plan view of the roadway centerline in an AutoCAD or Microstation format using only tangent lines and circular curves. Stationing was encouraged but not required.
- Profile view of the roadway centerline in an AutoCAD or Microstation format - Points were acceptable, however profile grades and parabolic vertical curves are encouraged.
- 3D break lines along the linear pavement markings in a CAD format
- Point and line attribute information tables for guardrail, utility covers, signs, bike lanes, sidewalks, among others.

Only three vendors submitted horizontal alignment for comparison, and fewer submitted complete point and line attribute data.

Reference lines within each roadway study location were created between two distinct surveyed points established with PK nails and reflective pavement marking tape. Elevation and intensity of points along the reference lines were extracted from the mesh grid fitted to LiDAR point clouds within a four-inch width at each station of interest. Due to the difference of reflectivity of the materials, which resulted in different intensities in the point cloud, the edge of the pavement, lane lines and centerline were readily extracted from LiDAR data by matching intensity and elevation results (see Figure 4.19). After which, the pavement cross slope for each travel lane was calculated by dividing the difference in elevations by the distance between two pavement markings. Additionally, pavement cross slopes were directly measured in the field for each test section using automatic leveling. Field measurements were used as reference data for comparison against vendor collected LiDAR derived data.

Shams et.al. (2017) used MLS to extract and evaluate the cross slope at 20 stations including 203 travel lanes. This research proved the feasibility of automated data collection vehicles in comparison to human collection methods to collect data efficiently, accurately, and reliably. The results of t-test statistical analysis indicated the average deviation between LiDAR data and field surveying measurements was less than the minimum acceptable accuracy value (±0.2% specified by SCDOT and SHRP 2) at a 95 % confidence level. It is noteworthy that even the unadjusted LiDAR data met the SCDOT standard.

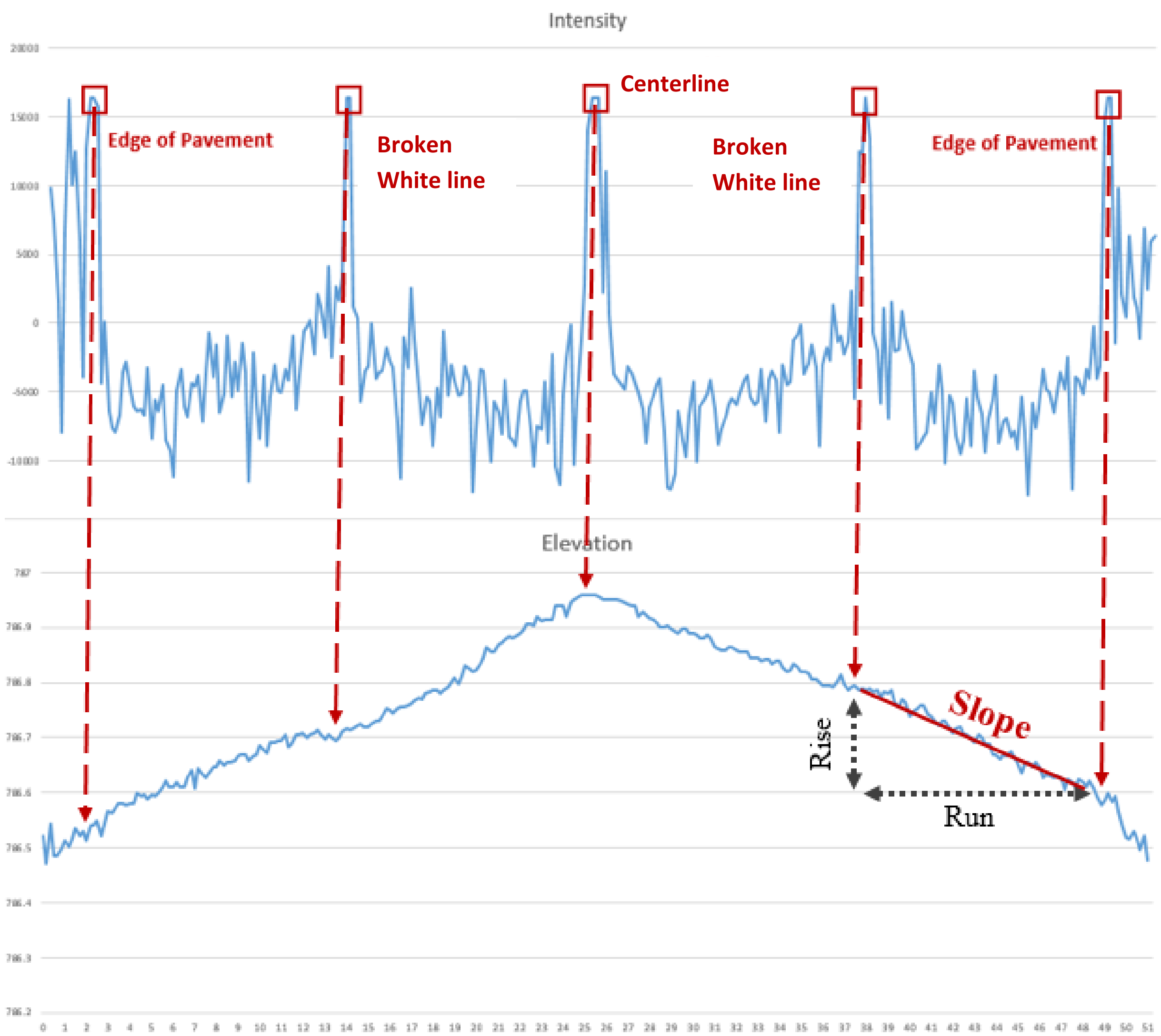
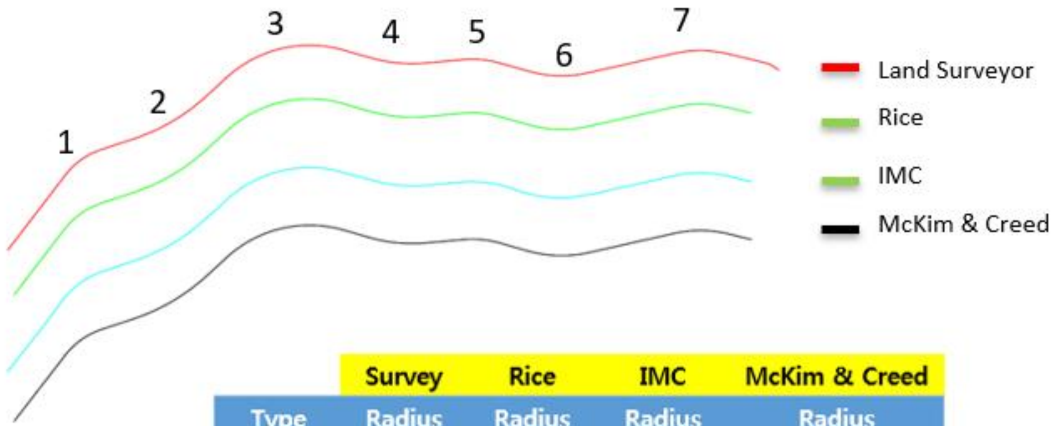


Figure 4.19 Pavement marking extraction and corresponding elevations

Figure 4.20 shows the test section horizontal alignment returned by the three responding vendors. Two vendors were consistently close (<125 feet) to the manual ground truth survey, and the third vendor had two readings that were 200-900 feet in difference. Most of the readings were within 50-60 feet, but one vendor was consistently within 5-10 feet of the surveyed measurement. The SHRP-2 accuracy recommendation for horizontal curve radius is 25 feet, and the one vendor achieved this accuracy level for 100% of measurements. Both other vendors were below 30% with respect to this threshold measure.



	Survey	Rice	IMC	McKim & Creed
Type	Radius	Radius	Radius	Radius
Curve 1	1432.41	1487.50	1667.71	1443.13
Curve 2	3819.72	3829.97	3829.81	3828.80
Curve 3	2291.83	2280.00	2311.49	2291.89
Curve 4	2864.79	2900.00	2297.29	2863.23
Curve 5	1909.86	1875.00	3132.17	1908.05
Curve 6	2291.83	2319.99	2360.71	2291.41
Curve 7	2291.83	2250.00	2574.22	2278.25

Figure 4.20 Horizontal Curve Radius Calculations

For the most part, the vendor with 100% horizontal accuracy within SHRP-2 ranges also had very good fit for the vertical curvature. However, as shown in Figure 4.21, there were issues on at least one vertical curve. Notice that the existing grade is not along the smooth section of centerline. Rather, in that section there is a raised median with vegetation that made the centerline elevations variable and higher than the calculated vertical curve surface. Situations such as this make validating the accuracy of the data more difficult, but these situations should not keep a vendor from passing an accuracy threshold. The test scenario that has been developed for this route captures numerous situations that truly test vendors and DOTs to find innovative solutions.

The break lines shown in Figure 4.22 represent the actual roadway very well. Even complex roadside concrete pads are nearly perfect in their capture. LiDAR also provides ability to obtain actual linear distances of pavement markings. If the LiDAR return amplitude is used to color the lines, differences between white and yellow can also be discerned. The break line graphics make it easy to discern the number and configuration of lanes as well as placement of on road control markings such as arrows and stop ahead notices. However, there will be instances as shown in Figure 4.18 where sections of the ground or slope alongside the road will be occluded from view.

In this graphic, the LiDAR encounters the guardrail and provides a return signal, and everything behind the guardrail is occluded. Black spots in the LiDAR cloud data represent this phenomenon.

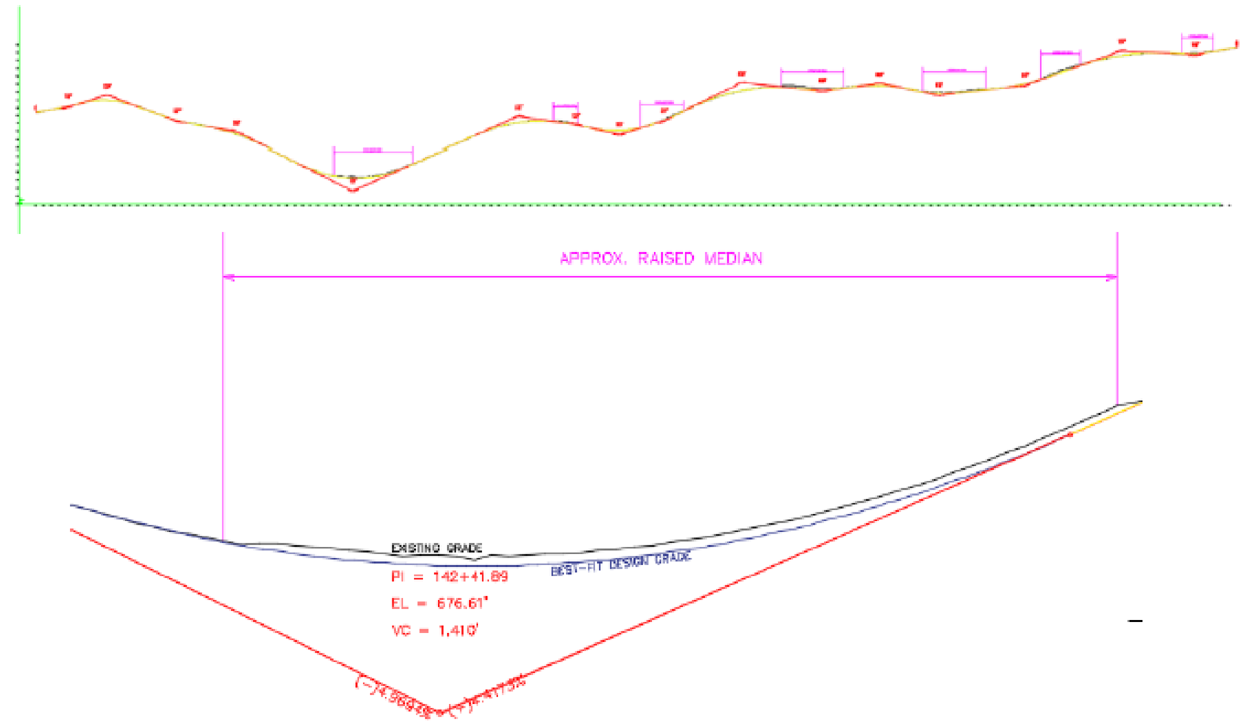


Figure 4.21 Vertical Curves and Existing Grades

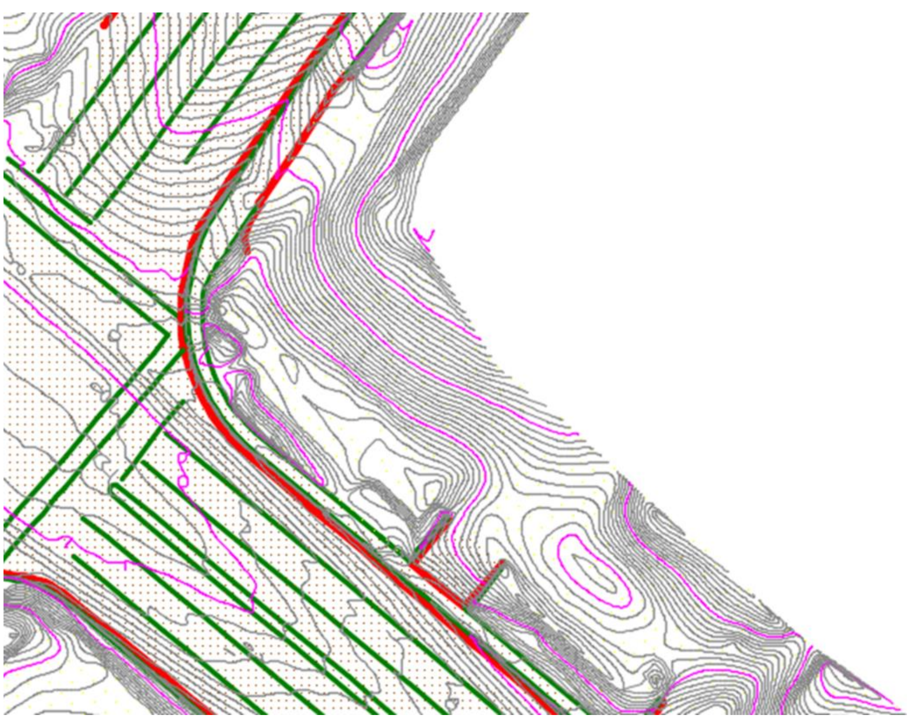


Figure 4.22 Example of Break lines and DTM

The research team requested numerous line and point data features from the vendors, but signage had the largest number of elements on which to compare vendors. Figure 4.23 shows the manual sign inventory conducted in the field prior to the vendor rodeo. It is interesting to note that the vendors detected many sign faces that the research team members did not. There were also a handful found by the research team and missed by the vendors. Table 4.20 shows signs in blue that were not detected by the vendor, yellow means not detected by researchers, and signs with no color were detected by both.

Figure 4.23 Manual Sign Inventory

Table 4.20 Comparison of manual surveyed signs and vendor detected signs

ID No.	X Coordinate (Easting)	Y Coordinates (Northing)	Direction	MUTCD Code	Legend or Description	Near IDNo	Near Dist	Missed by
59	1508954.153	995976.5013	East	M 1-2	Route sign	36	0.151	
59	1508587.796	996083.8975	West		Left Post, Truck Traffic Turn Right	-1	-1	research
58	1509173.431	995954.4993	East	D 9-2 + M 2-1	General Service Sign and Plaques + Junction Sign	39	0.38428	
57	1509296.887	995929.7817	East	W 3-3	Advance Traffic Control Signs	43	0.40497	
56	1509393.835	995909.9857	East	R3-8b	Advanced Intersection Lane Control Sign	45	0.04663	
55	1509490.578	995886.1261	East	D 1-2	Desitination Sign	47	0.61126	
54	1509748.746	995903.1213	West	D 14-3	Aknowledgment Sign (Adopt Highway)	53	0.41302	
53	1509351.777	996001.1445	West	R 2-1	Speed limit	55	0.19906	
52	1509035.284	996052.3215	West	W 2-2	Intesection warning sign	56	0.52181	
51	1508656.67	996069.2955	West	D 1-2	Guide Sign (School of Anderson)	57	0.61436	
48	1505430.994	995760.4579	West	D 3-1	Street Name Sign	-1	-1	vendor
38	1503909.111	995939.9879	North	R 2-1	Speed limit (Gallant Ln Street)	-1	-1	vendor
35	1508019.782	995854.3467	East	W2-2L	Side Road on Left	-1	-1	research
33	1505404.869	995652.6817	East	R9-5	Use Ped Signal	-1	-1	research
19	1499884.048	995511.3233	West	R2-1	Speed Limit	74	0.35776	
18	1499988.62	995501.5237	East	R 5-3	Regulatory signs and plaques for bicycle facilities (No motor vehicle sign)	12	0.11316	
17	1499764.249	995400.2253	West	D 14-3	Aknowledgment Sign (Adopt Highway)	75	0.15446	
16	1498789.967	994662.0107	East	W8-13	Bridge Ices Before Road Sign (Roadway Condition Sign)	-1	-1	vendor
15	1498162.488	994304.3761	East	W8-13	Bridge Ices Before Road Sign (Roadway Condition Sign)	8	0.30355	
14	1497056.799	993883.4919	East	R 2-1	Speed limit	80	0.16975	
14	1500071.305	995557.2993	East	R5-3	No Motor Vehicles	-1	-1	research
13	1497366.008	994104.5823	West	W3-5	Reduced speed limit ahead sign	78	0.25342	
12	1497113.095	993818.6065	East	R 2-1	Speed limit	7	0.10474	
11	1497164.221	993974.4297	East	W 2-2	Intersection warning sign	79	0.0453	
10	1496832.728	993654.3763	South	R1-1	Stop Sign (Driveway)	82	0.13898	
9	1494877.791	991930.2404	East	R 2-1	Speed limit	-1	-1	vendor
8	1496428.571	993081.6609	West	M 1-4	U.S route Sign	83	0.27285	
7	1496308.514	992924.2541	West	W3-3	Advance Traffic Control Signs	87	0.39725	
6	1496209.008	992801.4559	West	R3-8b	Advanced Intersection Lane Control Sign (Leg 2)	89	0.38679	
5	1496211.177	992799.5249	West	R3-8b	Advanced Intersection Lane Control Sign (Leg1)	88	0.46041	

Many of the signs that were overlooked by the research team were supplemental sign placards such as ‘Truck Traffic Turn Right’, ‘Use Ped Signal’, and ‘No Motor Vehicles’. Signs that were missed by the vendors were many, but the vendor with the most signs detected missed the ‘Adopt-A-Highway’ sign and a ‘Speed Limit’ sign that was sitting off to the side of a bicycle path (see Figure 4.24). In total, the research team identified 71 signs. The vendor with the most detected signs identified 39 additional signs and missed four signs that were identified by the research team. Thus, the best indication of the sign count would be 71+39 or 110. Out of the 110 signs, the highest detection vendor found 96%, and next highest were 87%, 44%, and 4%.

Figure 4.24 Examples of Missing Signs

Table 4.21 Vendor Sign Detection Summary

Vendor	# Signs Collected	# Missing Signs	# Additional Signs	Mean Distance	Standard Deviation
Mc Kim & Creed	49	23	11	0.67 ft	0.98
IMC	96	3	30	0.56 ft	0.59
Michael Baker	106	4	39	0.64 ft	0.55
Rice	4	62	0	0.15 ft	0.04
Quantum Spatial	--	--	--	--	--

Ultimately, MLS has great potential for asset data collection activities in South Carolina. This research has provided numerous examples from the vendor rodeo that meet and exceed data accuracy threshold levels set by the SHRP-2 including horizontal alignment, vertical alignment, and cross section details (including cross slope). For other variables, we have shown the ability of MLS to locate additional assets and attributes (e.g., sign inventory; presence of guard rail, cable rail, barrier, and clear zones; bridge characteristics such as clearance and span; and number of lanes using pavement markings).

The gap analysis was supported by information on accuracy, completeness, and uniformity of the SCDOT data and included a multi-level ranking of data needs. The priority data needs are clear. Further, LiDAR data collection covers over 70% of the priority data needs and is highly recommended.

Common survey data collection methods are time consuming and require data collectors to be located on the road, which poses a safety issue. However, new efficient methods such as MLS are available to capture accurate cross-slope, grades, location, and a variety of other geometric design characteristics. These new applications increase productivity and minimize road crew exposure and create robust information products that serve multiple uses such as flood mapping, hydroplaning, and materials estimating. The LiDAR data has many uses and cost savings for the DOT beyond inventory, and can even be funded across multiple state, city, and county partners as accomplished in Louisiana. Some examples of common MLS applications include: engineering surveys; roadway analysis; digital terrain modeling; 3D design, as-built or as-is documentation; quantities; drainage analysis; data acquisition during emergency response; clearances; forensic accident investigation; extraction of geometric properties for safety analysis; land use and zoning; BIM/BRIM; inventory collection; billboard inventory; historical preservation; landslide assessment; and virtual tourism.

CHAPTER 5: RECOMMENDATIONS

Throughout the results chapter, the research team highlighted noteworthy summaries and conclusions with respect to various tasks and analyses. Rather than restate these in duplicative manner, this final chapter will highlight a few key recommendations based on those findings.

5.1 Data as an Asset

In 2013, the AASHTO Core Data Principles shown in Figure 5.1 were adopted by the numerous committees and agencies including USDOT leadership. The first and most basic principle is that data is an asset – it is valuable. Data is a strategic asset of the organization. Data should support the business functions, and the business functions should support the agency and its mission. When data is treated as a capital asset, the agency needs to implement oversight, have an inventory of data systems, understand and communicate the quality of data, implement standard operating procedures for data development and maintenance, determine risks of data not supporting internal and external data customers, know who the data customers are, and ensure sufficient investment and fiscal oversight in this capital asset.

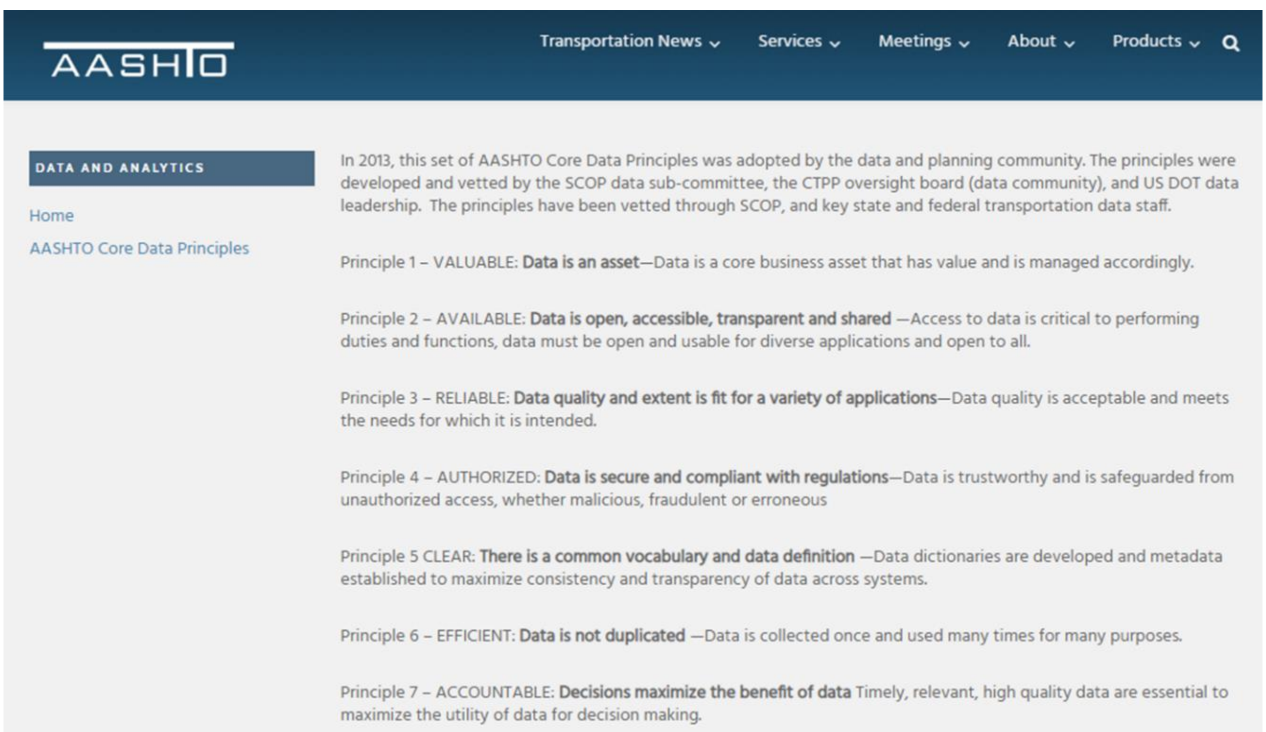


Figure 5.1 AASHTO Core Data Principles (Source: https://data.transportation.org)

Washington State DOT (WSDOT) has developed their principles to cover data and information as follows:

1) Data and information are critical to effective business decision making at WSDOT and shall be maintained in a manner appropriate to meet business needs.
2) Data and information are strategic, long-term assets owned by WSDOT, not by individual business units. They are findable, retrievable, and shared.
3) Data and information shall be collected once, stored once, and used multiple times.
4) Data and information that is not used shall not be collected or stored.
5) Data and information that is used by multiple applications or shared across business units shall be defined and managed from an enterprise perspective and fit for a variety of applications.
6) Data and information investments will consider business priorities, program impacts, and trade-offs.
7) Data and information shall be managed to provide availability, security, and integrity—they shall be both safe from harm and accessible by those who need them.
8) Data and information governance, costs, and stewardship processes will be transparent

Consider the two sets of questions below for managing two different types of assets – bridges and data. Most DOTs, if asked how many bridges they have, will be able to supply an answer in short order after pulling up the NBI database. In fact, the answers to almost all the bridge asset management questions are well known. However, when asked how many data systems a DOT has, the answer is typically vague, and a response may request additional clarification on what constitutes a data system. It is also unclear the total amount of money expended on data collection and management. For one database, the cost of data collection may be known, but total costs including department personnel that manage the data, the cost of data storage, and other IT maintenance costs for security and online access are likely too obscure to even estimate.

Managing Assets—Bridges	**Managing Assets—Data**
1. How many bridges do you have in South Carolina?	1. How many data systems do you have in South Carolina?
2. How far into the past/future do you assess/plan bridge projects?	2. How far into the past/future do you assess/plan data projects?
3. Number of staff associated with bridges management?	3. Number of staff associated with data management?
4. Budget/expenditures?	4. Budget/expenditures?
5. Chance for redundant construction or maintenance efforts?	5. Chance for redundant data collection or maintenance efforts?
6. Who are your bridge customers?	6. Who are your data customers?
7. Who defines the bridge management strategy?	7. Who defines the data management strategy?

SCDOT does not have a set of core data principles nor does it have a department-wide data business plan. There are data silos in various offices throughout department. At the most basic level, there is not an established business process to assess whether collecting a new data element(s) is justified, how many units it will serve, and what the cost impacts of maintaining the new data will be (e.g., contractor fees, storage, and data integration). These decisions should consider cross-department benefits and costs. The lack of structured decision-making processes and defined data management responsibilities can result in redundant data and data that may not be a high priority.

Recommendation - Raise the level of importance of data – treat it as an asset. Define core principles for data at SCDOT. Develop a department-wide directive or data business plan that recognizes the strategic uses of data across all business offices. Envision a plan to connect all the data assets to the enterprise system but maintained by experts in various offices. Determine where automated processes could free up staff for other purposes (e.g., for quality assurance and quality control, or user support).

Considering the new requirement for data collection on ALL public roads, SCDOT should be extending data collection or involving and incentivizing cities and counties to cost share to achieve the most efficient data collection to include rural minor collectors and locals. This shift would support data driven safety decision making for ALL public roads. This is important because a large portion of fatal crashes are not on roads for which SCDOT currently maintains data.

5.2 Data Governance

SCDOT currently lacks enterprise data governance; however, there are some pockets within the organization where governance activities occur. The Road Data Services Office, which handles a large portion of the GIS/Mapping, has been quite successful about setting up a statewide LRS and ensuring its use across the agency. Still, there are numerous offices that collect and maintain data throughout SCDOT that are not integrated or shared within the enterprise system (see

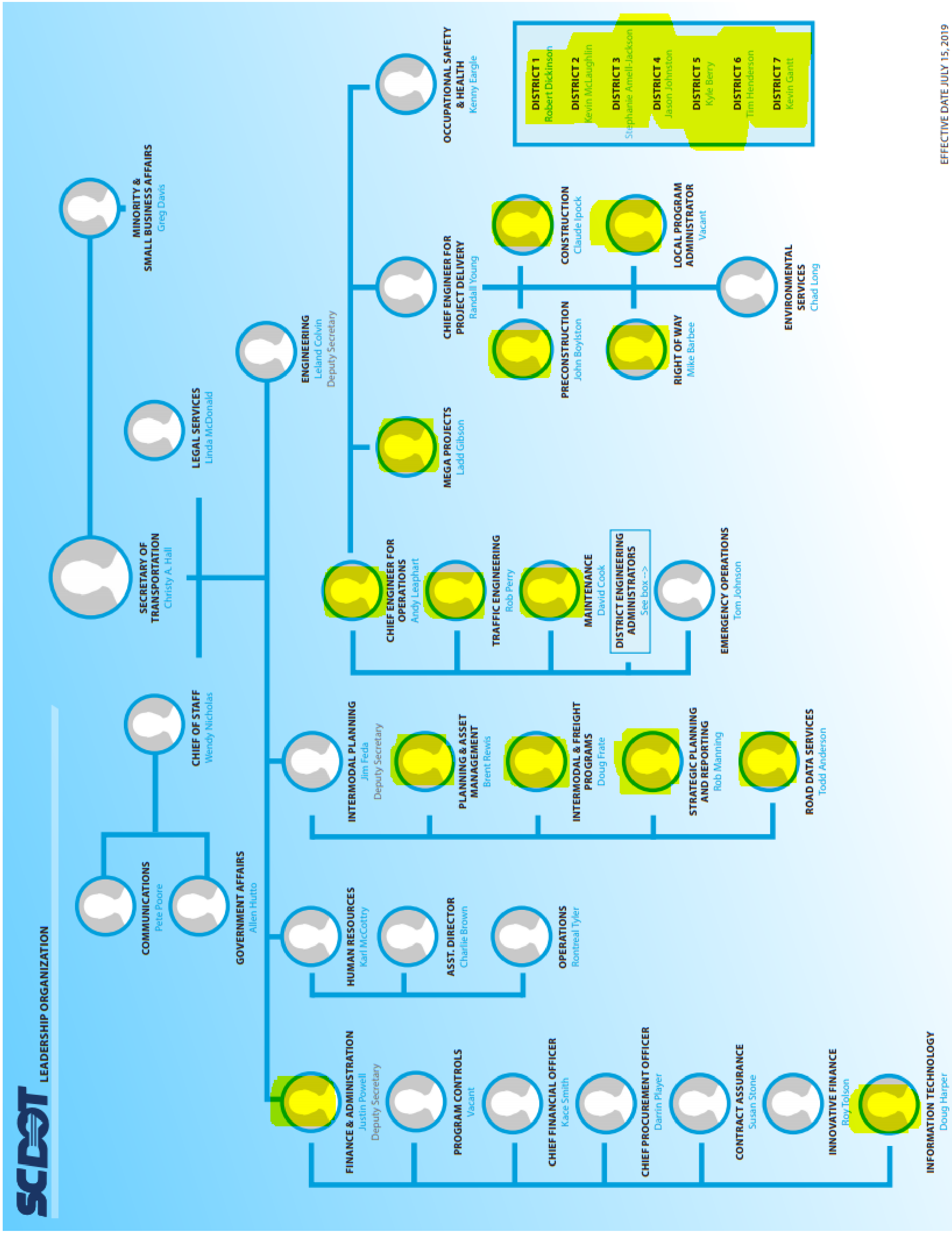


Figure 5.2). There is also no official coordination, policies, or approval process for making decisions regarding data assets. If an office decides to collect a new data element, there is no oversight group to make sure that:

- it is not a redundant data element maintained elsewhere in the department,
- there would be no cost-savings or efficiencies achieved should additional elements or services be collected simultaneously,
- it is a critical data need of the department and adheres to core data principles,
- it will be collected in a manner to allow integration with other data resources,
- it meets the documentation standards to include metadata and data dictionaries, and
- it has defined quality assurance and quality control mechanisms built into the data collection and maintenance process, as well as, meeting predefined measurable standards (e.g., completion, accuracy, and timeliness).

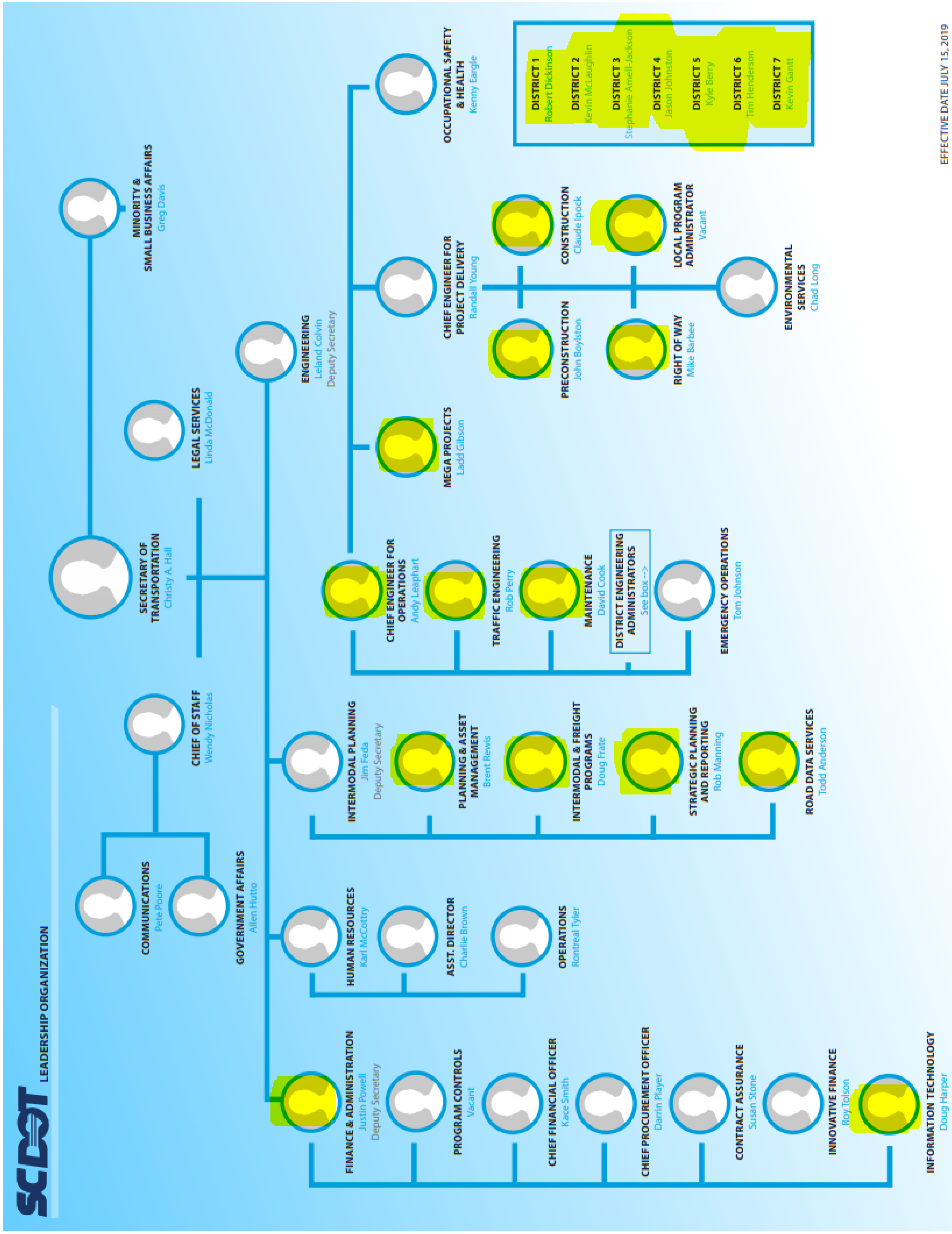


Figure 5.2 SCDOT Organizational Chart with Known Data Offices Highlighted

A recent NCHRP synthesis on "Data Management and Governance Practices at Transportation Agencies" found that only 19% of responding DOTs had a formal data governance structure in place, whereas, most agencies relied on bottom-up approach for data management. However, a top-down approach is more likely to identify, and value disparate data scattered across the department and seek solutions for integration and sharing within and beyond the agency. Lack of staffing, competing priorities, and lack of resources were identified by the majority of responding DOTs and local agencies as major factors in limiting progress towards implementing data governance. Having formally recognized data stewards was correlated with data sharing through warehouses or marts versus maintaining data in disparate siloed files when no such position exists. Most agreed that having increased use of web-based data storage and access, as well as improved database management systems, would improve data sharing and access.

The Florida Department of Transportation (FDOT) has been showcased as a leader in data governance after having developed their ROADS (**R**eliable, **O**rganized, **A**ccurate **D**ata **S**haring) initiative. According to the NCHRP report (2018), the initiative was formed with a goal to "improve data reliability, simplify data sharing across FDOT, and have readily available and accurate data to make informed decisions." This initiative stemmed from several issues identified by individuals or groups within the DOT (e.g., it's hard to know what data is available, data is hard to access, lack of standardized approach, no enterprise-level view of data, and teams want a 'one stop shop). (NCHRP, 2018)

The approach that was developed involves people, processes, and technology. The people are participants in the formal data governance structure, the processes are standardized routines to provide a formal approach to data governance, and the technologies are standard business intelligence and data warehousing tools and frameworks that make data and information more accessible.

The FDOT data governance structure has four levels with explicit roles and responsibilities as shown in Figure 5.3, but this could be streamlined to have only one middle group of data stewards. The modified structure might include the following groups and activities:

- The highest-level Executive Governance establishes policy and makes enterprise-wide, strategic governing decisions to assure the Department's goals and objectives are met. This group also is responsible for developing a charter and scoping the data governance program. At the start, this group may need to meet monthly. Once data governance policy has been established, this group may only need to meet quarterly or semiannually.
- The middle-level Data Stewards represent managers that oversee one or more data sets. This group enforces the policies enacted by the highest level and hears issues from the lower level. This group also coordinated across the Department to establish business rules for the data systems and provide the executive group with decisions needing higher approval or insight. This group is likely to meet every month or two.
- The lowest level Data Working Groups make day-to-day operational decisions, oversee individual data sets, and implement data management strategies. As issues arise needing

higher approval or coordination across the Department, they should be brought to Data Domain Stewards group. These working groups typically meet once per month or more. (NCHRP, 2018)

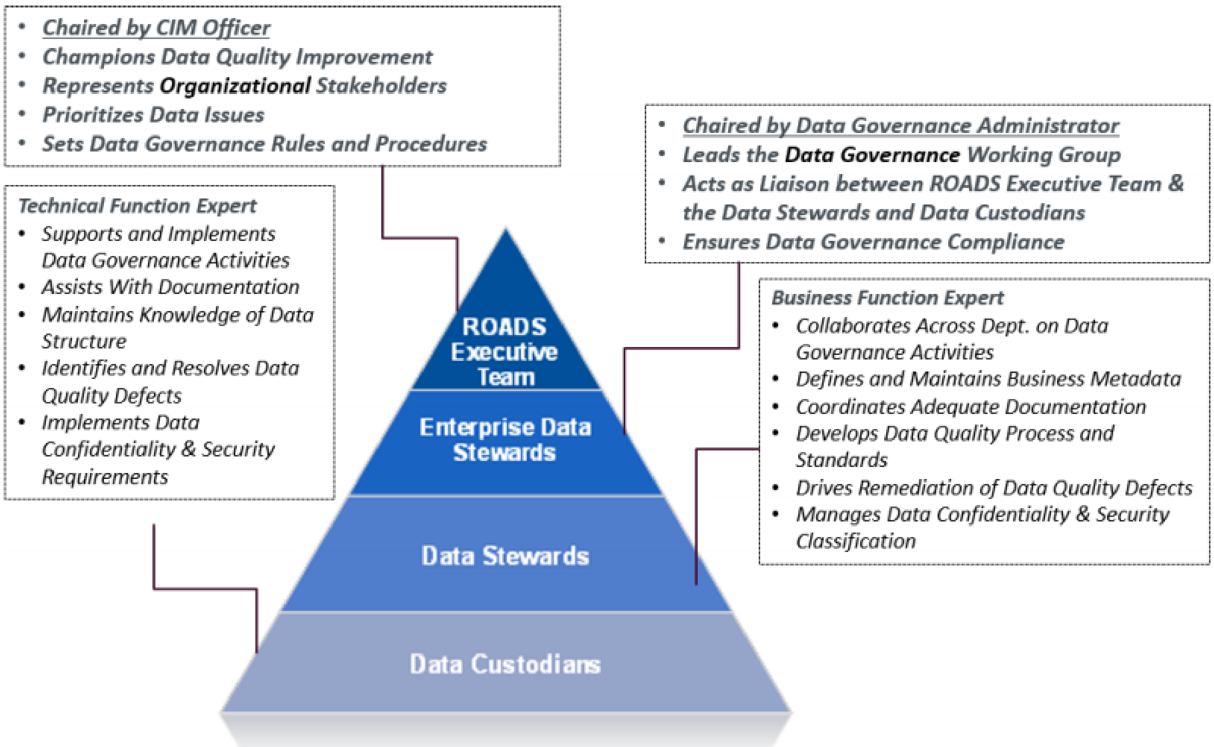


Figure 5.3 FDOT Data Governance Structure (NCHRP, 2018)

In addition to the main governance groups, a data governance coordinator is recommended to independently liaise between levels, schedule meetings and set agendas, distribute policy and meeting minutes, and other administration tasks. Having a coordinator is critical to the success of a data governance program.

Early meetings of each group will involve scoping and setting initial priorities for each group. Management and governance issues should be resolved at the lowest possible level within established authority and policy. As new issues arise, and existing policy does not cover them, the Executive Governance Council should enact new policies or prescribe how those issues should be handled in the future. Such policies could be proposed by Data Stewards for executive approval. All groups should only meet when there are agenda items to discuss so the meetings do not become obligatory and wasteful of staff's time. The coordinator should maintain a running list of important action items for each group to consider as agenda items.

Recommendation – Implement a tiered approach to data governance and appoint a dedicated data governance coordinator. The intent of this group is to promote structured decision-making and *active oversight of the Department's data assets. At SCDOT, there is currently a gray area where executives are not regularly involved in data decision making, but siloed data stewards and division staff do not have the authority to make enterprise-level decisions, such as:*

- *Establishing a mission and vision for data at SCDOT.*
- *Establishing procedures to understand roles and responsibilities for data governance, how decisions should be made, and foster coordination across silos.*
- *Defining the Department's core data systems (i.e., beyond Road Data Services) and the expected performance of those systems.*
- *Understanding staff utilization and how resources allocated to data management and data quality impact the Department's goals.*
- *Dictating a process for how data stewards and users should explain a business need for more or higher quality data.*
- *Documenting unfunded data needs and prioritizing available funding across business units.*
- *Deciding when to retire or continue to maintain aging systems and technology.*
- *Assuring data management staff have the authority and resources to do their jobs.*
- *Implementing and standardizing a change management process.*

SCDOT should develop an enterprise vision for its data systems. An enterprise mindset is necessary when prioritizing and funding data management and improvement activities. Managers should seek improvements that benefit many business units across the Department, rather than focusing on maintaining individual siloes of data. Staff should understand where the Department is going in terms of data improvements and be able to take the initiative to assure data supports the Department's mission and programs. Utilize the existing TAMP group to gain momentum for recommended governance changes and add others moving forward. Embrace transparency in data quality and work toward continuous improvement. Not all data at SCDOT is the best it can be, but realize that funding and staffing levels in individual offices have played a role in this, and data stewards often are doing the best that they can with what they have been given.

SCDOT should develop a clear plan to assure data systems and necessary improvements are appropriately and consistently resourced. With SCDOT programs relying on data and analysis more than ever before (e.g., asset management), the Department should assure an accurate, complete, integrated, and accessible roadway data system is adequately funded and that staff across the Department are trained and confident in managing and using the system. SCDOT should also define staffing needs and have a succession plan to minimize risks and impacts of staff turnover on Department business.

5.3 Mobile LiDAR Survey (MLS)

Currently at SCDOT, the Roadway Inventory Management System (RIMS) database is the main source for roadway attributes and is referenced using the LRS. Nearly 200 characteristics are contained in a single tabular format in Oracle. The original data from which the inventory is based is over 30 years old. While the inventory is updated using project plans, physical inventories are not regularly performed unless needed. The database is dynamically updated with new information within approximately two-weeks of receipt of a change record. A historical snapshot of RIMS is taken at the end of every year in December capturing all the changes that occurred since the prior snapshot. Roadway changes in any of the nearly 200 characteristics create new beginning and ending milepoints. Currently, data are only available for state-maintained roads except for city and county roads that are part of the HPMS sample frame. Keeping up with changes is challenging, especially for projects that are not funded directly through SCDOT (e.g., county sales tax projects) and files not shared in a timely manner.

Over just the last few years, numerous asset related research projects have been funded by SCDOT, and most have had either significant manual data collection, multiple database integration, or data recommendations, or all three. These projects include:

- *Sign Life Expectancy*, Dr. Nathan Huynh, University of South Carolina, FHWA-SC-18-02
- *Cross-Slope Verification using Mobile Scanning on SCDOT Interstates*, Dr. Wayne Sarasua, Clemson University, FHWA-SC-18-07
- *Development of SC Databases and Calibration Factors for the Highway Safety Manual (HSM)*, Dr. Jennifer Ogle, Clemson University, FHWA-SC-18-05
- *Best Practices for Accessing Culvert Health & Determining Appropriate Rehabilitation Methods*, Dr. Kalyan Piratla, Clemson University, FHWA-SC-17-01
- *Integration of the Incident Command System (ICS) Protocol for Effective Coordination of Multi-Agency Response to Traffic Incidents*, Jennifer Ogle, Clemson University, FHWA-SC-17-07
- *Ranking of Pavement Preservation Methods and Practices*, Dr. Brad Putman, Clemson University, FHWA-SC-16-05

For instance, on the *Ranking of Pavement Preservation Methods and Practices*, recommendations included, "Document additional information on preservation treatments to adequately track pavement preservation treatments," as well as, "Implement a more detailed pavement condition evaluation protocol to monitor the actual life extension of pavement preservation treatments. This process should include pre- and post-treatment condition assessment followed by routine evaluations on an annual basis."

During *Development of SC Databases and Calibration Factors for the Highway Safety Manual (HSM)*, researchers had to oversample sites by 25%. As each site was pulled up on Google Earth, and characteristics including the number of lanes, intersection traffic control, and median type were verified against the RIMS attributes. Approximately 15% of sites were discarded because they did not have fully matching characteristics for the particular site type. Ultimately, SCDOT is missing numerous site characteristics that are critical for site classification, crash assignment, and running state specific models.

NCHRP Report 748, "Guidelines for the Use of Mobile LIDAR in Transportation Applications," provides numerous potential uses for MLS point cloud data (See Figure 5.4). The array of uses covers project development, asset management, safety, operations, maintenance, among others. One thing to consider when acquiring MLS data for a state are the accuracy and density requirements for various applications. The more detailed the need, the more accurate and dense the point clouds need to be. Approximate accuracy and density for these applications can be found in Table 5.1.

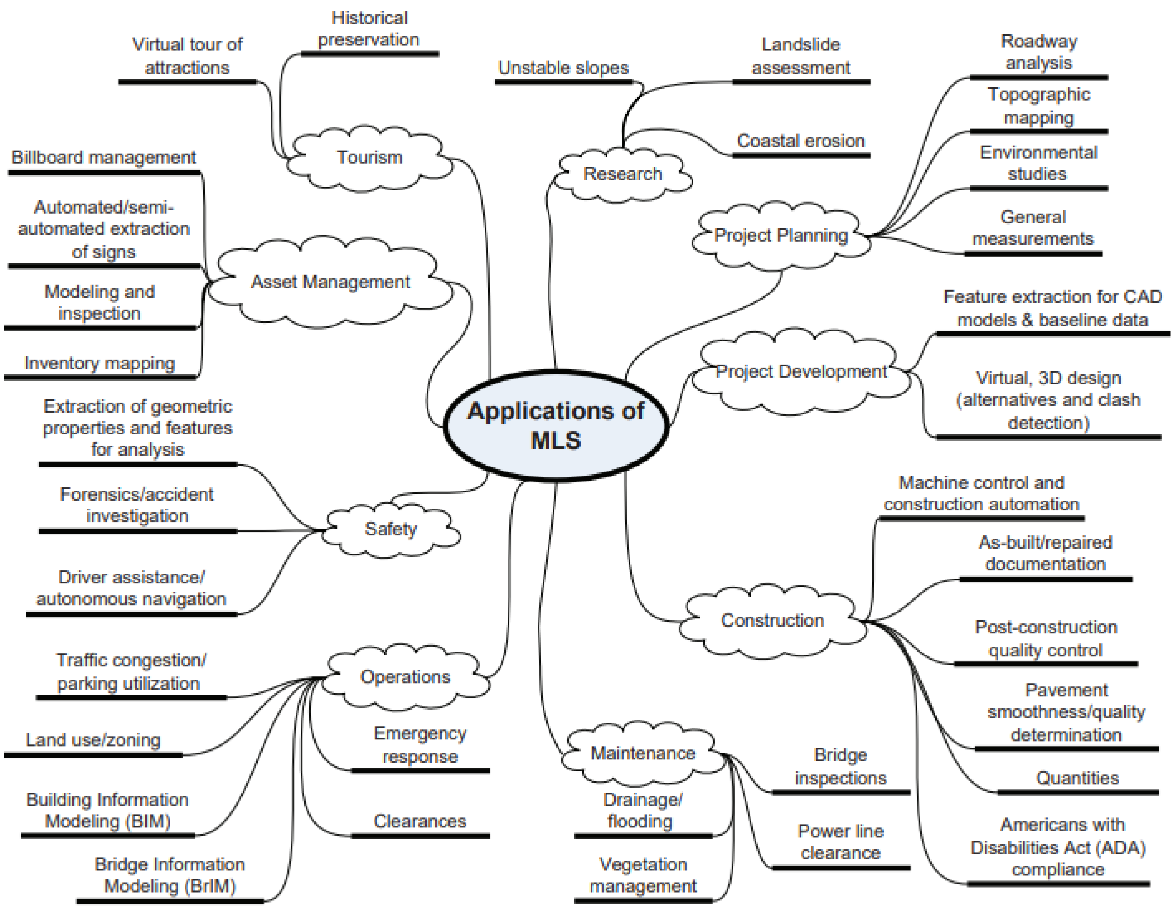


Figure 5.4 Applications of MLS

Table 5.1 Accuracy and Density of Point Clouds for Various Applications

Accuracy	HIGH < 0.05 m (< 0.16 ft)	MEDIUM 0.05 to 0.20 m (0.16 to 0.66 ft)	LOW > 0.20 m (> 0.66 ft)
Density	**1A**	**2A**	**3A**
FINE >100 pts/m^2 (>9 pts/ft^2)	• Engineering surveys • Digital terrain modeling • Construction automation/ Machine control • ADA compliance • *Clearances** • *Pavement analysis* • Drainage/Flooding analysis • Virtual, 3D design • CAD models/Baseline data • BIM/BRIM** • Post-construction quality control • As-built/As-is/Repair documentation • Structural inspections	• *Forensics/Accident investigation** • *Historical preservation* • Power line clearance	• Roadway condition assessment (general)
	1B	**2B**	**3B**
INTERMEDIATE 30 to 100 pts/m^2 (3 to 9 pts/ft^2)	• Unstable slopes • Landslide assessment	• General mapping • *General measurements* • Driver assistance • Autonomous navigation • Automated/Semi-automatic extraction of signs and other features • Coastal change • *Safety* • Environmental studies	• Asset management • Inventory mapping (e.g., GIS) • Virtual tourism
	1C	**2C**	**3C**
COARSE <30 pts/m^2 (<3 pts/ft^2)	• *Quantities (e.g., earthwork)* • Natural terrain mapping	• *Vegetation management*	• Emergency response • Planning • Land use/Zoning • Urban modeling • Traffic congestion/ Parking utilization • Billboard management

**Network accuracies may be relaxed for applications identified in red italics.*
**BIM/BRIM: BIM = Building Information Modeling; BRIM = Bridge Information Modeling.
These are only suggestions; requirements may change based on project needs and specific transportation agency requirements.

Several states have begun to collect MLS data over the last few years, but Utah is a front-runner with respect to scale and documenting process and gains. In 2011, they were the first to write an RFP which was awarded to collect statewide mobile LiDAR data services. The project started off to gather surface distress data, but a data champion at the agency realized that there was potential more that could be done with the data beyond distress. A coordinated effort identified multiple offices collecting redundant data and with gaps in the data that needed to be filled. The diversity of partners allowed for "economies of scale" procurement processes and spread funding requirements across multiple offices and divisions. (Utah LiDAR Case Study)

In Utah, there are over 41,000 centerline miles, with approximately 6,000 state-maintained centerline miles and 19,000 miles of unpaved roads. The data collection was planned for the 15% of state roads carrying 67% of the vehicle miles traveled in the state. The $2.5 million project was funded in nearly 3 equal parts using HSIP funds, SPR funds, and State funds. $1 million came from the existing pavement survey, and maintenance, traffic, and safety funded the additional $1.5 million. (Utah LiDAR Case Study)

A similar project was also undertaken in Lousiana, where LADOTD decided to collect the MIRE fundamental data elements on all public roads in three two-year cycles. LADOTD plans to share the data with local agencies and has arranged for additional data to be collected for locals at a reduced fee. The Baton Rouge MPO contracted with the vendor in partnership with LADOTD, and has estimated a 46% cost savings for the data collection on nearly 4,000 centerline miles of roadway (datacollect_la3).

The UDOT Roadway Imaging and Inventory contract required collection of specific roadway assets, including:

- Roadway condition data
- Roadway photolog
- Pavement photolog
- Number, length, and type of lanes
- Ramps and collectors
- Median and barrier presence (type and width)
- Guardrails, shoulder barrier, and end treatments
- Striping and pavement messages
- Bike lanes
- Intersections (quantity, type, and signal equipment)
- Bridges, overhead obstructions, and other structures (with clearances)
- Surface areas and pavement width (with adjacent pedestrian facilities)
- Lane miles
- Sign supports and faces
- Striping and pavement markings

- Shoulders
- Rumble Strips
- Curb and Gutter
- Drainage features (mainly drop inlets)

The asset data were collected in layers that are easily used in a geographic information system environment and reduce redundancy of flat file format. Each layer is set up for a specific elment and contains only information that pertains to that element. Having point features such as signal poles in a single layer makes it easy to know exactly how many signal poles the agency owns and categorized by type.

The MLS has allowed UDOT to examine roadway features from the office rather than in the field with an estimated savings of $200,000 in annual labor costs as shown in Table 5.2. Additionally, the MLS data has been "retroactively mined" for information that was not on the needs list when the project began. This has provided an additional cost savings of almost $600,000 or 80% per year (see Table 5.3).

Table 5.2 Potential for Office Data Collection vs. Field Data Collection

Use Case	Prior Time and Cost	New Time and Cost	Labor-Only Savings	Non-Quantifiable Benefits
Billboard inventory and measurements	90 days $144,000	2 hours per region: $400	$144,000	Many billboards are extremely difficult to access in the field
Highway Performance Monitoring System (HPMS) reporting	3,300 hours $55,000	700 hours $35,000	$20,000	Data can now be updated every year, per-diem and overtime costs are saved
Bike corridor inventory	300 hours $15,000	0.5 hours $25	$15,000	This information was not previously available for project planning and bike-friendly state ranking

Table 5.3 Labor Savings from "Retroactively Mining" Data

Use Case	Prior Time and Cost	New Time and Cost	Labor-Only Savings	Non-Quantifiable Benefits
Create project summary sheets for pavement preservation and rehabilitation projects (75 projects)	6 days/pr. $180,000	1.5 days/pr. $45,000	$135,000	Fewer change orders and more accurate estimates
Develop preliminary project estimates (30 Concept Reports)	100 hours $150,000	10 hours $15,000	$135,000	More accurate estimates, better responsiveness to public due to faster reporting
Identify safety improvements that can be made with projects (40 Operational Safety Reports)	$7,500/proj. $300,000	$2,500/proj. $100,000	$200,000	Higher quality analysis with more recommendation options, able to perform analysis quickly in programming and scoping phase
Assess safety elements and crash conditions using usRAP and BYU Safety Modeling (5,000 miles)	0.5 hr./mile $125,000	40 hours $2,000	$100,000	N/A

Recommendation - Given these issues, as well as the positive results from the vendor MLS rodeo, the research team highly recommends undertaking a new inventory of roadway attributes as well as other roadside assets (e.g., culverts, signs, bikeways, pedestrian facilities, and ADA). After 30 years, it is time to refresh the roadway inventory, discern quantities to a degree not possible in the past, add missing features that represent key assets, and capitalize on additional opportunities for MLS point cloud data.

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APPENDIX A – ITMS DATA DUMP SUMMARY FILE

APPENDIX B – COLOR-CODED MASTER SHEET

APPENDIX C – FULL GAP LIST FOR MIRE VS SCDOT

***All appendices are located in digital file*