Integrated Sign Management System – ADOT Maintenance Group

Final Report SPR 451

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16. Abstract –

The Arizona Department of Transportation maintains and manages an inventory of roadway signs. Before the implementation of this project, sign technicians maintained inventory records on individual laptops to track their daily sign maintenance activities. Each individual laptop contained sign file data that pertained only to the installed signs within the area in which the sign technician worked. It was difficult to share information and generate management reports. In addition, some sign regions did not even use their laptops to maintain the inventory records for their signs, but used paper forms to complete their daily work.

To meet this challenge, ADOT has developed an application to:

- Track the installation, maintenance and replacement of all ADOT roadway signs
- Provide for the maintenance of data pertaining to the attributes of all ADOT roadway signs statewide
- Satisfy the dynamic business requirements, especially in the area of predicting sign replacement by allowing the database design to easily incorporate other factors into the prediction formula.

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SI (MODERN METRIC) CONVERSION FACTORS*

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
	AREA			
mm^2	Square millimeters	0.0016	square inches	in^2
m^2	Square meters	10.764	square feet	ft^2
m^2	Square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
	VOLUME			
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	Cubic meters	35.315	cubic feet	ft^3
m^3	Cubic meters	1.308	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (or "metric ton")	1.102	short tons (2000lb)	T
	TEMPERATURE (exact)			
°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
	ILLUMINATION			
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
	FORCE AND PRESSURE OR STRESS			
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

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ABBREVIATIONS

AASHTO .....American Association of State Highway and Transportation Officials
ADOT .....Arizona Department of Transportation
AIDW.....Arizona Information Data Warehouse
ASP .....Active Server Page
ASTM .....American Society for Testing and Materials
ATRC.....Arizona Transportation Research Center
EG .....Engineering Grade
FHWA.....Federal Highway Administration
FGPR.....Florescent Grade Prismatic
FIS.....Features Inventory System
FPG .....Fluorescent Prismatic Grade
GIS .....Geographical Information System
GPS .....Global Positioning System
HIG .....High-Intensity Grade
HIPR .....High Intensity Prismatic
IE.....Internet Explorer
ITG.....Information Technology Group
ISPMMS .....Integrated Sign and Pavement Marking Management System
Lat .....latitude
Long .....longitude
MOAS.....Manual of Approved Signs
MMS .....Maintenance Management System
MUTCD .....Manual of Uniform Traffic Control Devices
NPA.....Notice of Proposed Amendments
PeCoS.....Performance Controlled System
RFI .....Request For Information
SEG.....Super Engineering Grade
SFO .....Sign Fabrication Ordering
SHPR.....Super High Intensity Prismatic
SMS.....Sign Maintenance System
TAC.....Technical Advisory Committee
TIAMS .....Transportation Infrastructure Asset Management System

1 EXECUTIVE SUMMARY

In November of 1999, the Arizona Department of Transportation (ADOT) began looking at a new way of automating the management of roadway signs. It developed a system that it calls SMS (Sign Management System). Although it took over two years to define the system's requirements and design it, SMS now provides an administrative system for tracking and reporting all maintenance activities regarding ADOT roadway signs. In addition, SMS supports the logistics, planning and reporting of all sign maintenance activities. The vision was to build SMS to serve as a model for future maintenance systems.

The SMS application resides within the framework of the current ADOT Maintenance Management System (MMS) architecture. The SMS performs 2 primary functions:

1. Asset Inventory: The SMS uses predictive equations and methods that aid sign maintenance crews in managing sign installation and replacement. The system also maintains data on the physical attributes of all signs statewide.

2. Work Management: The predefined management algorithms improve budget planning and making of daily work orders. In addition, data pertaining to the labor, materials, and equipment utilized is downloaded into the Performance Controlled System (PeCoS). Data relating to sign condition and maintenance history resides only in the PeCoS application.

SMS provides the ability to predict future maintenance activities for a sign. The application is robust enough to accommodate changes in formula values as needs arise. Currently, SMS prediction formulas use sheeting manufacturers' warranties, installation date, and facing direction to calculate a sign's life span.

The application has recently been rolled out to all sign maintenance regions in Arizona. Although it may take time to realize all the benefits of SMS, it has certainly provided a better method of predicting the life expectancy of a sign, which can only help ADOT from a risk management standpoint. It will also provide a better mechanism for tracking and managing ADOT roadway signs.

The biggest concerns or questions involve the extent to which the system will be used and the adoption of new technology. These two factors greatly influence the success or failure of any new system deployed today.

2 INTRODUCTION AND OBJECTIVES

2.1 BACKGROUND

The Arizona Department of Transportation maintains and manages an inventory of roadway signs. Before the implementation of this project, sign technicians maintained inventory records on individual laptops computers where they tracked their daily sign maintenance activities. Each technician's laptop had data on only the signs within his work area. Because these laptops were operated independently of one another, and the data was only locally stored, it was difficult to share information and generate management reports. It was cumbersome for supervisors to get access to sign records within their own region. There was no easy way of seeing data for signs in other sign regions across the state. Moreover, some sign regions did not use their laptops to maintain their sign inventory records, but used paper forms to complete their daily work.

In addition to entering daily sign activities on their laptops or on paper, sign technicians were also required to enter daily work report data into the PeCoS system. Some of the entry into their laptops and into PeCoS contained the same information. This duplicate entry of data was labor intensive and error prone.

Finally, the sign file system had no way to predict replacement dates of installed signs. This put ADOT at risk because of the retroreflectivity of the installed sign and limited ability to properly budget for the replacement of signs. The liability issue is directly related to lawsuits filed against ADOT when drivers claim a sign is not clearly visible. The visibility of the sign at night is the result of the sign's retroreflectivity.

2.2 RETROREFLECTIVITY STANDARDS

The American Association of State Highway and Transportation Officials (AASHTO) proposed the following four criteria for evaluating retroreflectivity: [Ref. 1]

1. Minimum sign retroreflectivity values: This method requires the measurement of signs with retroreflectometers on a regular basis. Signs are to be replaced when the measured values approach minimum values.
2. Minimum nighttime sign legibility distances: This method requires nighttime inspection to ensure the legibility of signs within a particular distance. Signs are to be replaced when the sign is no longer legible at a specified distance.
3. Nighttime visual sign inspection by trained observers: This method requires 'calibration' of the inspector's eyes with sample signs near retroreflectivity limits established by research.
4. Maximum service life of signs: This method requires determining sheeting types in use, determining the expected life of those sheeting types, and setting up a replacement program to ensure signs are replaced prior to the end of their expected service life.

ADOT chose #4 to predict sign replacement dates.

2.3 SCOPE OF THE PROJECT

2.3.1 Main Goals

The scope of this Arizona Transportation Research Center (ATRC) Research project was to provide an application to:

- Track the installation, maintenance and replacement of all ADOT roadway signs.
- Provide for the maintenance of data pertaining to the attributes of all ADOT roadway signs statewide.
- Satisfy the dynamic business requirements, especially in the area of predicting sign replacement.

To facilitate prediction of the maintenance and replacement of all ADOT roadway signs, the application stores data on each sign, such as installation date, maintenance activities and other sign attributes. Reports generated by the system include Inventory Detail (which lists all details of a sign including predicted replacement dates), a count of signs along any stretch of roadway, and detailed activity reports.

To provide for the maintenance of data on the attributes of all ADOT roadway signs statewide, the application provides for the maintenance of the individual attributes of each sign. These sign attributes include the type of sign, dimensions, color, message, responsible sign organization, sign-facing direction, number of support legs, geographic location, maintenance record, replacement date, removal date, and the date and time of installation.

This is a distributed system with the data being stored in two places: first in a single database installed on each laptop. These single databases contain only data pertinent to the individual sign organizations. Sign technicians enter their data offline into the databases on these laptops while working on the roadways. Second, the data is stored in the centralized Features Inventory database, of which Signing is a Feature Category. Reports are generated from the data in the Features Inventory database.

Through a data-synchronization routine the data is transferred from the individual laptops to the Features Inventory database, and likewise, the laptops receive updates from the Features Inventory database.

With this type of distributed system, data is available statewide and can be drilled down to the individual asset level. Figure 1 illustrates the SMS data flow and system integration:

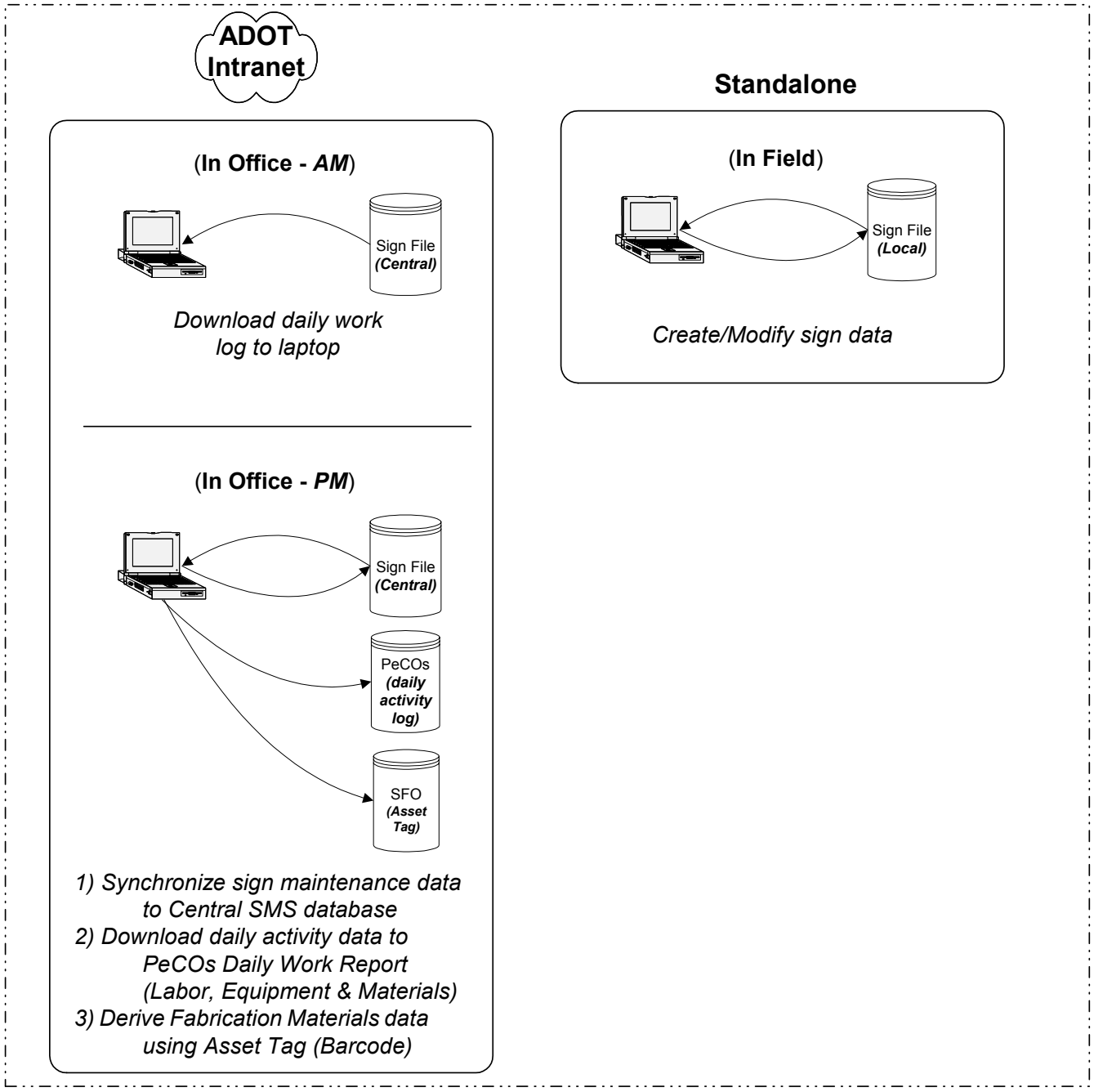


Figure 1 SMS Data Flow and Integration

To ensure the system is robust enough to meet dynamic business requirements, particularly in predicting sign replacement dates, ADOT has identified the following four factors for SMS to use to determine a sign's life span:

1. Orientation of the sign.
2. Color of the sign.
3. Sheeting material.
4. Sign technician's discretion.

The sheeting manufacturer's warranty is the base figure. If there is more than one manufacturer's sheeting material is used on the sign, then the figure for material with the shortest guaranteed life is used. Other factors may or may not detract from the original value. If a particular factor is deemed to not have a degrading affect, it is given a value of one (1), which nullifies its consequence.

Initially, it was thought that elevation and environment would be factors. However as ADOT does not have altimeters installed in the sign technician trucks, it was determined that using elevation as a factor would not be feasible. It was also determined that environment would not be feasible. A sign's orientation can greatly affect its life span. Signs facing south lose their retroreflectivity (and life span) much faster than signs facing north. The color of a sign also affects its life span simply because some colors lose retroreflectivity faster than others.

The sheeting materials, such as Super Engineering Grade (SEG), Engineering Grade (EG) and Prismatic, have different manufacturers' warranties. The SEG has the longest warranty, and therefore is given the longest lifespan in SMS. EG has the next longest life span, followed by Prismatic. ADOT policy dictates the type of sheeting material used to create a sign based on the Manual on Uniform Traffic Control Devices (MUTCD) type; i.e. regulatory, standard.

Calculation of a sign's replacement date is based on its orientation, color and sheeting material. However, a sign technician may set a new date if he sees that a sign will need to be replaced sooner than the predicted replacement date. Please refer to Figure 4 Sign Screen Predictive Tab on Page 14.

One additional ADOT-specific policy involves uniqueness of a sign. Since each sign is unique once it is installed, a loss of this uniqueness might occur if a previously installed sign is moved to a new location. In consideration of the cost of a new sign vs. the unknown loss of the uniqueness of moving a sign, it is ADOT policy that all permanently installed *regulatory* and *warning* signs not be relocated from their original location regardless of their apparent remaining life. If the location of a permanent regulatory or warning sign has to be adjusted, a new sign is to be installed and the previous sign is to be scrapped.

2.3.2 Business Objectives

The key business objectives of this project were to provide a rules-based, functionally robust and integrated sign management system. Requirements of the system included:

- Business rules and logic that were revisable within the system via data entry rather than program modifications.
- That it would:
  - Predict future sign maintenance.
  - Time/date stamp the installation
  - Keep a maintenance log.
  - Keep track of replacement or removal of any roadway sign.
- The system had to integrate with other Maintenance Management systems such as PeCoS so as to reduce the re-entry of data and with the Features Inventory system for storage of the centralized data. Also, an interface with the Sign Fabrication Ordering (SFO) system was required so that sign attributes, bar codes, etc. could be derived from that system.

2.3.3 Technical Objectives

The technical objectives were to have a distributed system that would facilitate data entry both online and offline, and to create system interfaces. The system was designed for use with Windows 2000 or NT Server, MS SQL 2000 Relational Data Base Management System, Intranet Server, Microsoft Visual Basic 6.0, and an application tool-set that supports Extensible Markup Language (XML) and Microsoft Active-X Data Objects (ADO).

3 SIGN PREDICTIVE REPLACEMENT

3.1 SIGN PREDICTION REPLACEMENT PROBLEM STATEMENT

Guidelines for predicting when signs should be scheduled for replacement based upon their expected degradation of retroreflectivity did not exist. ADOT therefore developed the Sign Management System, which uses sheeting material life expectancy, color and exposure factors to predict each sign's life span. The system allows inclusion of additional factors as their impacts are understood and quantifiable. This report gives the data sources, and explains the database design and formula used to predict sign life span and replacement dates. [Ref. 2]

3.2 DESIGN OF SIGN REPLACEMENT PREDICTION FUNCTION

Fabrication of a sign may include more than one grade of sheeting material. It will be important to record the most limiting grade of sheeting material used in fabrication to determine the sign's life expectancy. History has shown that a signs "size" and "color" significantly impacts its life expectancy. Also, the environment at a sign's location can cause extra wear. A sign's life expectancy should be adjustable to account for size, color, and environmental factors where possible.

The Sign Fabrication component determines the type of sheeting material, size, and color. These factors are also derived within the Sign Management System along with the Installation Date and Retroreflectivity Direction Facing Factor. The predicted replacement date becomes the sign's life expectancy.

Since temperature and precipitation contribute to increased sign wear and reduction of retroreflectivity, the Roadway Sign Technicians perform routine inspections of signs. Based upon their observations and personal experience, they may shorten the replacement date at their discretion.

If in the future, it is decided that additional factors (i.e., elevation, roadway speed, precipitation) are needed to calculate the predictive replacement date, the database is designed to allow for easy incorporation of additional factors.

3.3 SIGN PREDICTIVE REPLACEMENT TECHNICAL DESIGN

3.3.1 Maximum Sign Life of a Sheeting Material

The Sign Fabrication component lists the type of sheeting material, size, and color. These factors are also included within the Sign Management System.

Before a Sign Factory staff marks a sign order as "fabricated", they enter data on the materials used into the Sign Fabrication Ordering System. Though the background sheeting material is most significant for cost analysis, it may not be the most limiting in regard to retroreflectivity loss. Sign Factory staff enter data on the sheeting material with the shortest retroreflectivity life expectancy into a separate field.

All sheeting materials used by the Sign Factory are listed in the SMS on a Maximum Sign Life Sheeting Material Table, with "Life Expectancy in Years" derived from Federal Highway Administration (FHWA) guidelines.

Table 1 Maximum Sign Life / Sheeting Material

Code	Sheeting Material Abbreviation	Description	Life Expectancy in Years
I	EG	Engineering Grade	7
II	SEG	Super Engineering Grade	10
III	HIG	High Intensity grade	15
IV	HIPR	High Intensity Prismatic	15
VII	SHPR	Super High Intensity Prismatic	15
VII	FGPR	Florescent Grade Prismatic	15

3.3.2 Adjustments of Life Expectancy Based on Size and Color

As mentioned previously, size and color are significant factors in predicting retroreflectivity longevity. The "Sign Catalog Maintenance Table" in the SMS contains certain 'Special" signs and a complete listing of all signs located in the Manual of Approved Signs (MOAS). Where practical, the size and/or color factors of the sign are provided in the Sign Catalog record. For signs normally found in the Sign Warehouse inventory, the stock number is also provided.

The Sign Catalog Maintenance Table provides the data to take into account a sign's size and color when calculating its life expectancy.

Table 2 Sign Catalog Maintenance

Sign Catalog Number	Stock Number	Size	Color	MOAS	Name	Picture	Sign Type	Approval Required	Life Expectancy for EG Sheeting	Life Expectancy for SEG Sheeting
143	92D115	24 x 48	Orange	W1-6	Large Arrow (Single Arrowhead)		Standard	No	2 yrs	5 yrs
144	36A375	24 x 48	Yellow	W1-6	Large Arrow (Single Arrowhead)		Standard	No	7 yrs	10 yrs
145			Green	D2-2	Destination Mileage (2 Destination listed)		Standard	No	6 yrs	9 yrs
146	35D726	26 x 6	Brown		Ski Area		Special	Yes	5 yrs	7 yrs

Note: The initial values for the Life Expectancy column in the "Sign Catalog Maintenance Table" will be loaded from the "Maximum Sign Life Sheeting Material Table" values above. The Integrated Sign Management System will have a maintenance screen where authorized Sign Factory personnel, engineers, etc. can modify these values.

3.3.3 Adjustments of Life Expectancy Based on Exposure

The direction an installed sign faces (exposure) also affects retroreflectivity longevity. The Retroreflectivity Facing Direction Maintenance Table in SMS contains a facing direction factor that is used to determine the Life Expectancy of the sign.

Table 3 Retroreflectivity Facing Direction Factors

Facing Direction	Facing Direction Factor
North	1
South	1
East	1
West	1

Note: The initial values for the Retroreflectivity Facing Direction Factor are defaulted to 1. Since *Facing Direction* was not an attribute that existed until the implementation of the SMS, no history data is available to determine what this factor should be. The SMS has a maintenance screen where authorized Sign Factory personnel and engineers can modify these values. ADOT will evaluate and appropriately adjust the 'facing direction factors' as data becomes available.

3.3.4 Predictive Replacement Date Calculation

The Predicted Replacement Date is calculated for in-service, installed signs, based on the following formula:

Sign Life= ((Sheeting material life expectancy ***(stated in terms of years)*** * Facing Direction Factor) * Sign Color Factor)

Predicted Replacement Date = Install Date + Sign Life

Though the formula is simple, determining a sign's life expectancy depends on whether or not the sign is in the Sign Catalog. Four separate scenarios are considered and a demonstration on how these values are produced involve the following:

- The sign is listed in the Sign Catalog Maintenance Table? (i.e. – adjustments for color and size are possible)
- The sign is not listed in the Sign Catalog Maintenance Table? (in which case the retroreflectivity sheeting material entered on the "Sign Screen-Predictive Tab" will be used to find the sign life expectancy from the Maximum Sign Life Sheeting Material Table)

Scenario 1 – Sign Made in Sign Factory AND Is Listed in the Sign Catalog:

This scenario may occur for:

- A sign order for a standard sign
- A sign order for a special sign

Look Up In:

- "Sign Catalog Maintenance Table"

Based On:

- "Sign Catalog ID" field entered on the "Sign Order Screen"

- "Retroreflectivity Sheeting" field entered for the sign on the "Sign Screen".
    - This value is initially populated with the "Retroreflectivity Sheeting" field entered for the sign order on the "Sign Fabrication Screen".

Look Up In:

- "Sign Facing Direction Maintenance Table"

Based On:

- "Sign Facing Direction" field entered for the sign on the "Sign Screen".

Scenario 2 - Sign Made in Sign Factory AND NOT Listed in the Sign Catalog:

This scenario may occur for:

- A sign order for a special sign

Look Up In:

- "Maximum Sign Life Sheeting Material Table"

Based On:

- "Retroreflectivity Sheeting" field entered for the sign on the "Sign Screen".

- This value is initially populated with the "Retroreflectivity Sheeting" field entered for the sign order on the "Sign Fabrication Screen".

Look Up In:

- "Sign Facing Direction Maintenance Table"

Based On:

- "Sign Facing Direction" field entered for the sign on the "Sign Screen".

Scenario 3 - Sign NOT Made by Sign Factory AND Is Listed in the Sign Catalog:

This scenario may occur for:

- Existing sign already installed on the roadway (includes interstate and some special signs)
- New Interstate sign

  Look Up In:
  - "Sign Catalog Maintenance Table

  Based On:
  - "Size", "Color" and "MOAS" field entered on "Sign Screens", which interprets the Sign Catalog Number

- "Retroreflectivity Sheeting" field entered for the sign on the "Sign Screen"

  Look Up In:
  - "Sign Facing Direction Maintenance Table"

  Based On:
  - "Sign Facing Direction" field entered for the sign on the "Sign Screen".

Scenario 4 - Sign NOT Made in Sign Factory AND NOT listed in the Sign Catalog:

This scenario may occur for:

- Certain existing special sign already installed on the roadway

  Look Up In:
  - "Maximum Sign Life Sheeting Material Table"

  Based On:
  - "Retroreflectivity Sheeting" field entered for the sign on the "Sign Screen"

  Look Up In:
  - "Sign Facing Direction Maintenance Table"

  Based On:
  - "Sign Facing Direction" field entered for the sign on the "Sign Screen".

The following three “Sign Screens”, Summary, General, and Predictive exist in tabular form in the SMS.

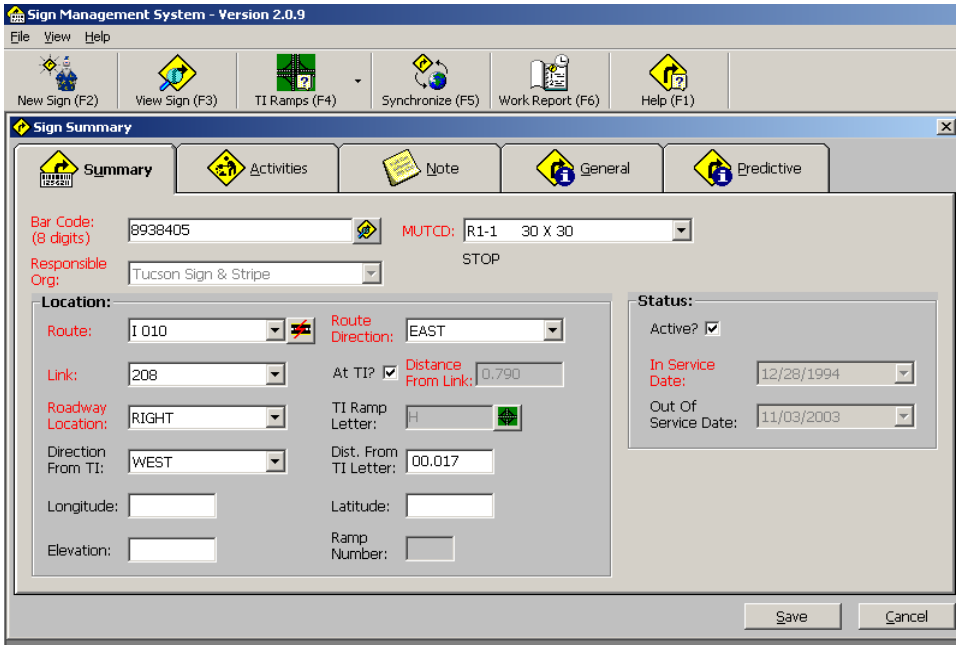


Figure 2 Sign Screen Summary Tab

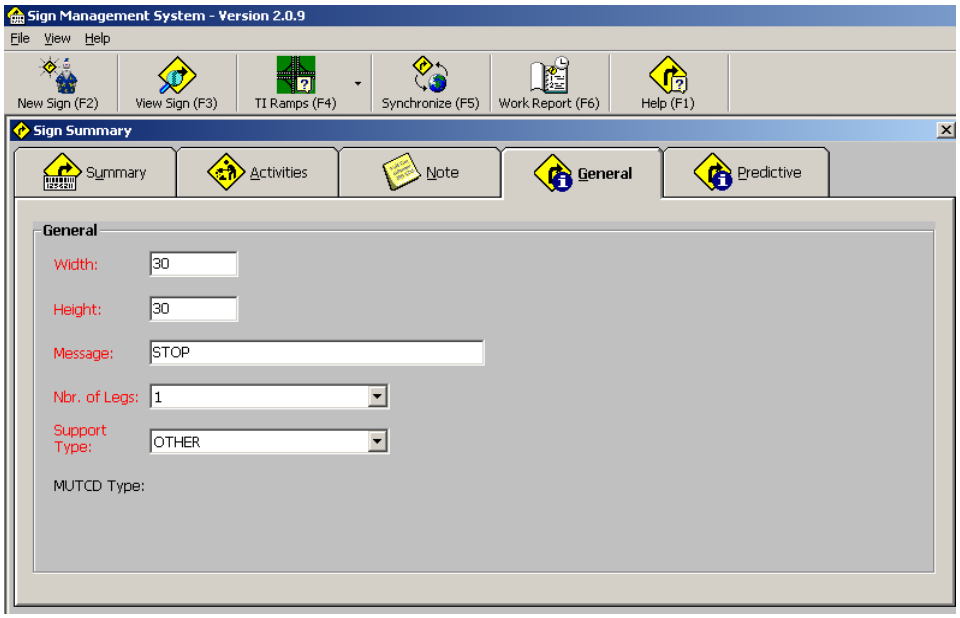


Figure 3 Sign Screen General Tab

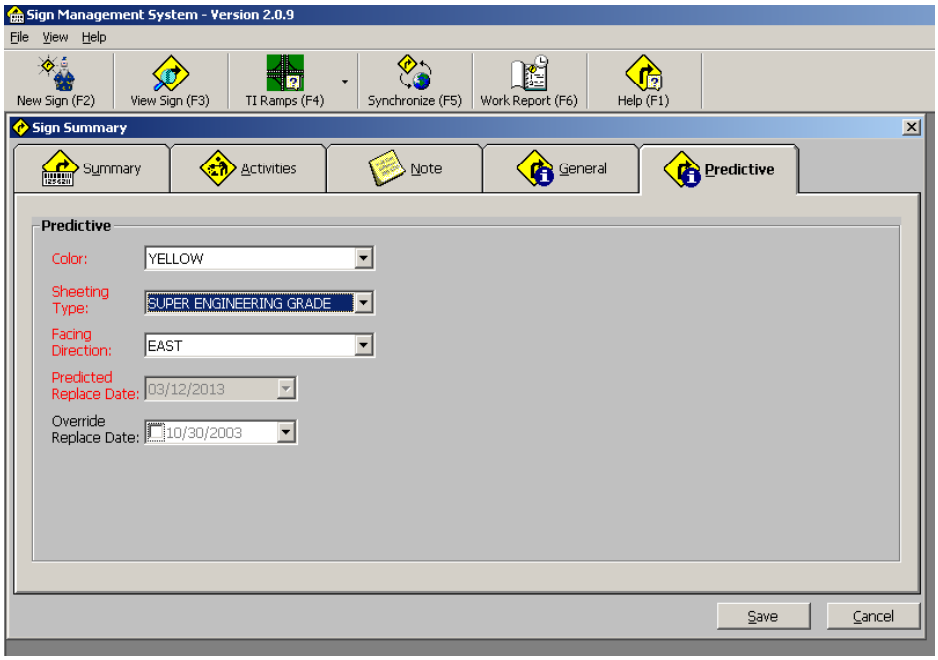


Figure 4 Sign Screen Predictive Tab

NOTE: Currently, there is no sheeting material information captured for the existing installed signs on the roadway. Therefore, the "Retroreflectivity Sheeting" field will be defaulted to engineering grade. However, the Roadway Sign Technician will have the capability of modifying the "Retroreflectivity Sheeting" field on the "Predictive Sign Screen".

4 SIGN MANAGEMENT SYSTEM (SMS) OVERVIEW

4.1 PROBLEM STATEMENT

ADOT's Sign Maintenance Section had a tremendous need to keep a current accurate database of all maintenance assets across the state. The legacy Regulatory Sign File System was outdated; the data was not reliable and was very error prone. It also did not allow data sharing between stand-alone laptops. The new SMS tracks the installation, maintenance and removal of signs on ADOT roadways for legal, risk management, and planning purposes. The data is available to any ADOT employees that need it. SMS also predicts when signs should be scheduled for replacement based upon their expected degradation of retroreflectivity.

The revised edition of the MUTCD will have provisions for maintaining retroreflective values on signs above specified minimum levels. Once these new requirements are in effect[1], increased liability exists if signs are not maintained above the set minimums.

A need existed to determine the accuracy requirements, data needed, and reporting formats necessary to develop and maintain a sign management system. There was also a need to develop an accurate inventory of all of signs, and a Sign Maintenance System.

Implementation of SMS has satisfied the requirement to have an accurate inventory of all signs. Later phases will address the accurate inventory of all pavement markings.

4.2 RESEARCH OBJECTIVES

The objective of this research project was to develop the elements and requirements necessary to maintain and operate a network level Sign Management System, and then develop and implement the SMS.

4.3 PROJECT OBJECTIVES

The Sign Management System helps streamline and improve the current business processes for ADOT Sign Maintenance personnel. SMS was designed to support two different types of client configurations and is capable of operating via a network, stand-alone workstation, or laptop. This system replaces the legacy Regulatory Sign File System.

[1] Although the revised edition of the MUTCD (MUTCD 2000) has now been published, as of June 14, 2001, no official standards have been released or published for either signs or pavement markings. See Reference section.

The major objectives of this application was to achieve the following:

- An integrated sign maintenance system for tracking the installation and maintenance of all ADOT signs. Every maintenance action involving an installed sign from installation through cleaning and repair to replacement will be recorded similarly to the method used by the legacy sign file system. The Sign Management System will track the maintenance actions of signs installed and removed on ADOT's roadways.
- To have the ability to track/monitor sign retroreflectivity via visual inspection. This inspection ability will include the function of indicating a starting and ending milepost for a stretch of roadway being inspected. The installed inventory of that roadway will be scanned and all signs for that span found in the travel direction will be selected for scrolled viewing with a default inspection status of "PASSED." Individual sign records may be selected for indicating a status of "FAILED." When this event takes place, the user will be given the opportunity to make notes documenting the failure. In a future phase of this application, the FAILED status could lead to a mandatory entry of FAILED reason. Certain reason codes will generate a repair or replace work order.
- To have the ability to enter maintenance work activities one time and eliminate the duplicate entry process.
- An interface with the Features Inventory System.
- A system for scheduling sign replacement based upon retroreflectivity.
- A robust reporting system for both on-screen and hard copy documentation.

The Sign Management System includes the following functionality for the Highway Sign Technicians, Highway Sign Supervisors, Arizona Information Data Warehouse, Transportation Infrastructure Asset Management System, and ADOT Maintenance Management:

- Full management of sign installation and maintenance activities of all ADOT signs
- Ability to track the location, physical condition, retroreflectivity level, details, support and post information for signs on the entire ADOT base road network.
- Ability to track sign maintenance activities for a specific location for planning and decision-making purposes.
- Incorporates a predictive tool to automatically predict sign replacement dates based on retroreflectivity sheeting material life expectancy, color, facing direction, and install date.
- Incorporates precedence validation rules for maintenance actions regarding a sign to ensure data integrity so inconsistent maintenance actions are not entered for the same sign.
- Automatic generation of various sign detail, statistical, and managerial reports.
- Ability to use the system from a laptop not connected to the network and synchronizes data with the master database in Features Inventory System.

- Ability to detect signs that are missing.

4.4 SOFTWARE SOLUTION

ADOT provided an application that:

- Replaced the legacy Regulatory Sign File application with the new SMS.
- Centralized the repository using advanced relational database technology.
- Modernized the interface with efficient, Windows compliant, user-friendly modules.
- Provided intuitive automated tools that track the installation, maintenance, and removal of ADOT roadway signs.
- Provided an accurate reporting system for risk management, maintenance management, and field personnel needs.
- Collects daily work activities out in the field and feeds PeCoS, thus reducing duplicate entries by maintenance staff.
- Communicates and feeds data to the Features Inventory System database.
- Provides user adjustable, predictive modules for the replacement of ADOT roadway signs based upon their expected degradation of retroreflectivity and other relevant factors.

4.5 HARDWARE SOLUTION

ADOT refreshed or upgraded existing servers, laptops and workstations necessary to run the Sign Management System. Additionally, any hardware/software changes, upgrades, or replacements to the Wide Area Network were also completed.

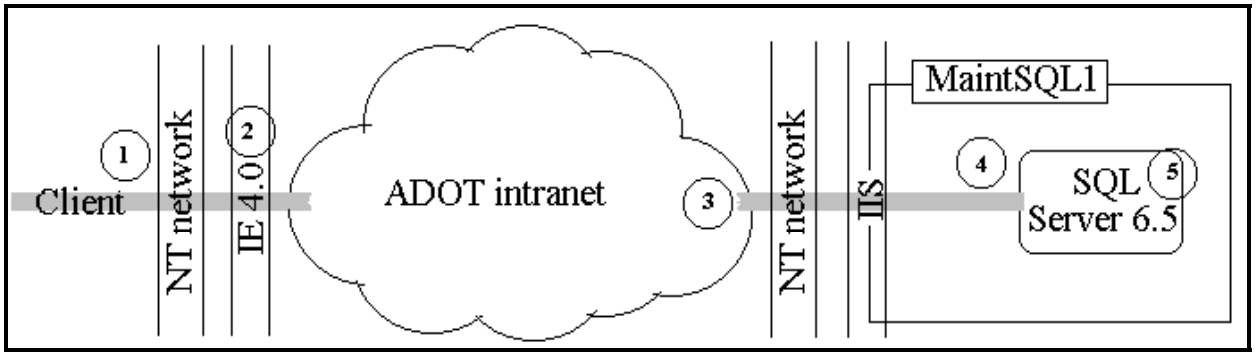


Figure 5 Centralized SQL Server Design

4.6 PROJECT HISTORY SUMMARY

This project was originally put out by procurement in a Request For Information (RFI) to determine whether such an application already existed, either by a vendor or other transportation entity. The focus was on retroreflectivity, sign and pavement marking, and predictive replacement in an enterprise level management system. The responses were less than encouraging. The majority of the products found were designed for small, municipality scale transportation systems. None had all of our requirements.

Due to the limited resources available at the time, the project was broken down into phases. It was hoped that both pavement markings and signs could be managed in the first phase. However, after review of available products, and following more detailed database and module design, it was decided that the funds available would only cover development of the Sign Management application. The database would, however, be robust enough to handle point, linear, and area data. Volume would not be addressed at this time.

Another reason for delaying the pavement markings retroreflectivity tracking portion was lack of information from AASHTO at the time of development. The plan was to track Signs and Pavement Markings for the purposes of using predictive equations and methodologies to predict the expiration of minimum retroreflectivity. We had all the information needed for signs but not for Pavement Marking. This could be added to the system later when more information and funds become available.

4.7 RELATIONSHIP WITH FEATURES INVENTORY SYSTEM

The Features Inventory System (FIS) is the core database for the Maintenance Management System. The SMS database resides within the framework and architecture of the FIS database. It stores basic information for each feature type, however any particular business rules for any feature type will be addressed by that feature type's own management system. For instance, signs require certain business rules; thus the Sign Management System will handle these rules.

4.7.1 FIS Technology Characteristics:

- *Distributed system:* Intranet end-user interface, Active Server Page (ASP) with Visual Basic scripts, XML, and Active Reports. End users access the system using Microsoft Internet Explorer. Data entry is done at the District level. Data is stored in a Central Database allowing for statewide reporting.
- *Integrated system:* As mentioned above, the system integrates with other modules of the Maintenance Management System. This helps reduce duplicate entry of data.
- *Platform-compliant system:* The system complies with ADOT's current and planned IT Platform. This platform consists of Windows 2000 Server, MS SQL Server 2000 Relational Database Management System.

4.7.2 Interface from Sign Management System (SMS) to FIS

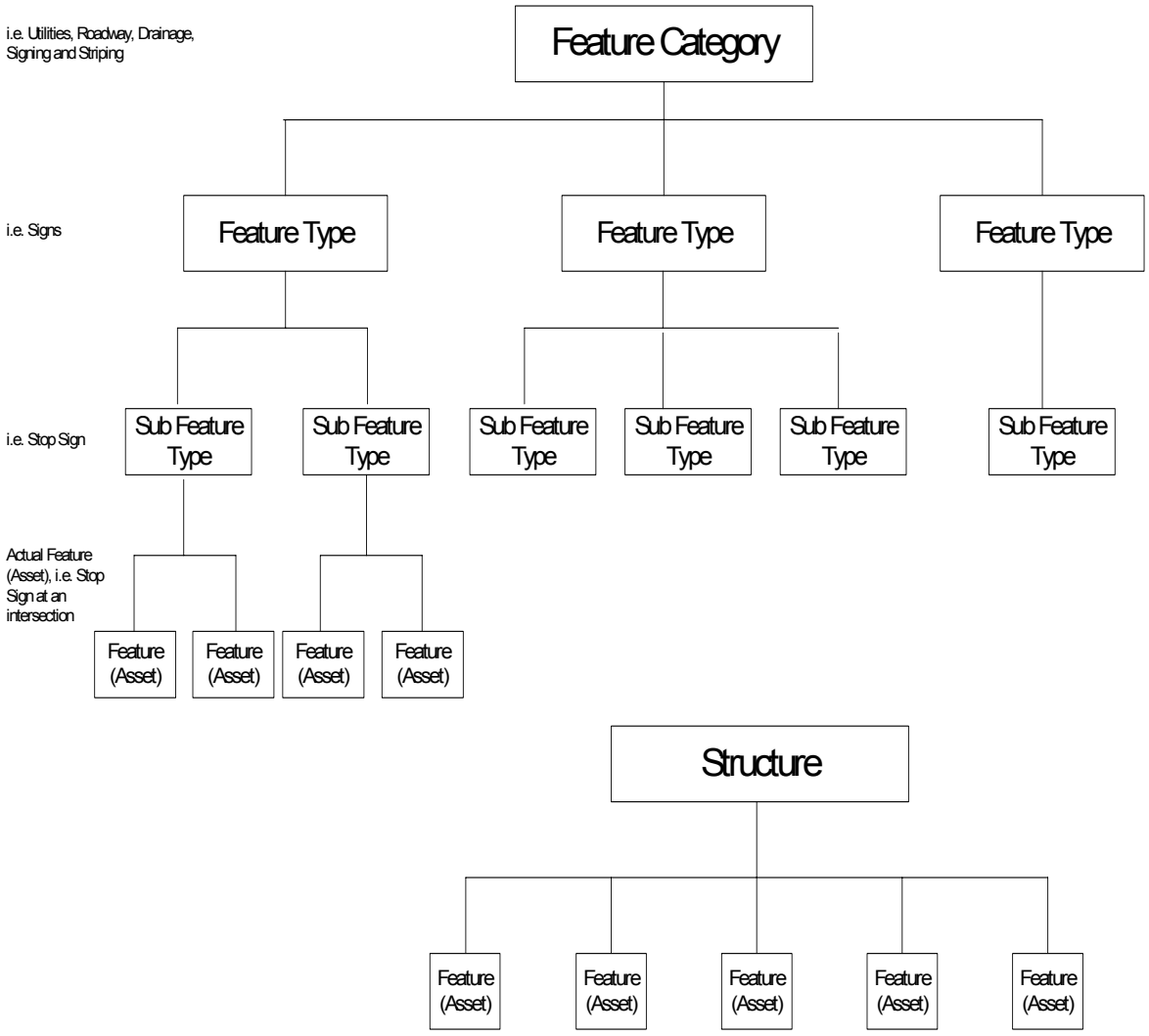
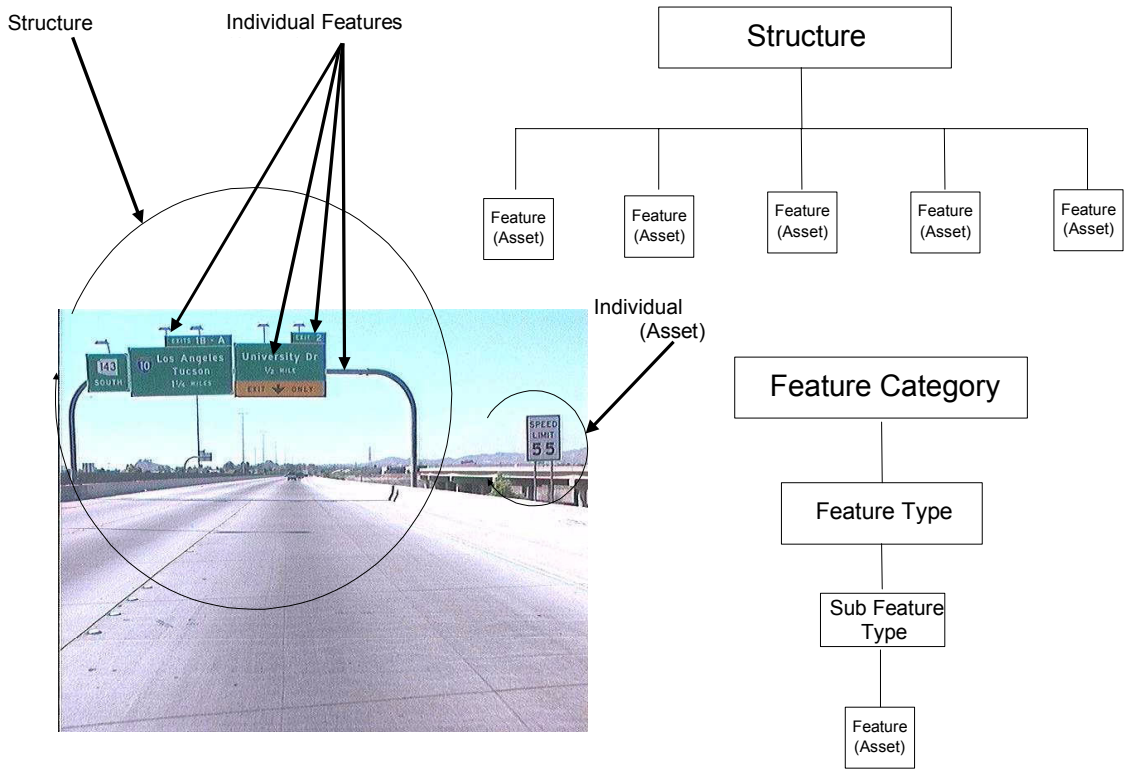


Figure 6 FIS Hierarchy Examples



Individual Features (Assets) located at the same geographical location can be part of and assigned to a "Structure".

Regardless of this, each individual Feature or Asset will have a Sub Feature Type. Each Sub Feature Type will be part of a Type. Each Feature Type will be part of a Feature

Figure 7 FIS Structure Example

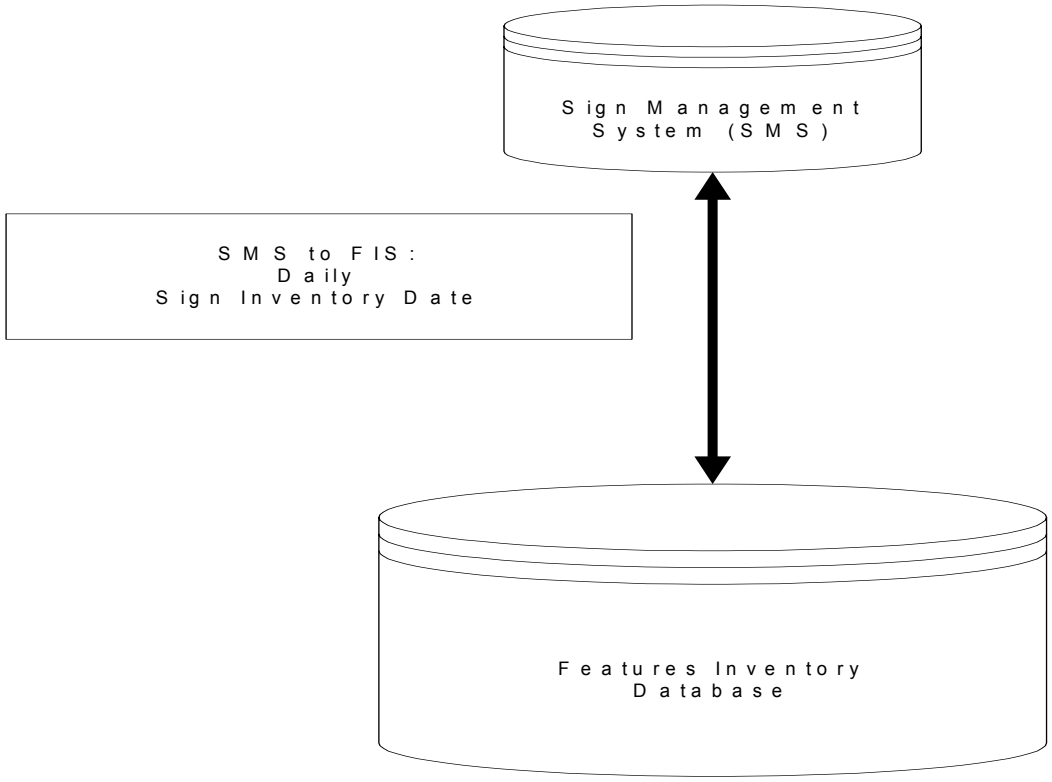


Figure 8 SMS to FIS Data Flow

4.8 BENEFITS OF SMS

ADOT will have accurate information on all signs, including current and historical data. This information will enhance the ability to conform to new government regulations, to accurately predict maintenance needs, and to set schedules. In addition, it will increase public safety, increase organizational efficiency, and reduce costs (some of which will be legal or risk management).

4.8.1 Process Improvement Savings:

1. Supports continuous process improvement.
2. Provides an environment in which existing processes can be codified before staff knowledge is lost.
3. Provides transaction integrity by ensuring that proper procedures are followed.
4. Improves productivity by better distribution of work.
5. Manages the work "pipeline" to address priority tasks.
6. Performs concurrent processing of work tasks.
7. Shortens the cycle-time of many processes.
8. Identifies bottlenecks.

4.8.2 Additional Cost Savings:

Direct Cost Savings:

- This project facilitates pre-loss efforts to prevent collision and the ensuing human suffering. The project also provides assistance in preventing litigation and for defense in litigation.

Indirect Cost Savings:

- Eliminates the duplicate data handling and application data entry.
- Automates non value-added functions such as monitoring form progress, error checking, exception handling and adherence to policy.
- Focuses on value-added functions.
- Eliminates redundant reviews, approvals and handling functions.
- Reduces cost, improves accuracy and provides quicker response to repetitive requests.
- Reduces or halts the growth of administrative resource needs.

4.9 IMPACT IF SMS WAS NOT DEVELOPED:

- Delays in the production of signage could have compromised public safety.
- Federal regulations may not have been met in a timely manner (i.e. signs that need retro fitting for new retroreflectivity standards).
- The inability to accurately predict maintenance schedules for signage could have result in increased costs in labor, equipment and materials.
- Increased risk and liability when the inventory and maintenance records are not accurate.
- Increased risk and liability when the missing or destroyed signs are not replaced.

4.10 LEGAL REQUIREMENTS:

The state and federal laws requiring maintenance of the highway system, including signs and stripes are ARS 28-1863 and Federal Law Title 23, Chapter 1, Paragraph 116: Maintenance. The federal law states, "It shall be the duty of state highway departments to maintain, or cause to be maintained, any project constructed under the coverage of this chapter, or constructed under the provisions of prior acts."

Retroreflectivity Mandate: Federal standards for retroreflectivity are expected to be forthcoming. Without the Sign Management System in place, it would be unlikely that ADOT could provide the necessary information to support compliance.

5 CONCLUSIONS AND RECOMMENDATIONS

The Sign Management System has just recently been released to the various ADOT regions. It is much too early to assess the impact SMS has had on ADOT or if it accomplished all the goals set forth at the beginning of this project. A comprehensive field test over an extended period of time needs to take place before we can measure the true value of the system as it applies to ADOT. Once in place and users become comfortable using the software, ADOT will have a much better idea as to its impact on the Department. What we do know now is that the implementation of SMS provides steps to move forward in managing the life expectancy of signs by utilizing a better method of predicting life expectancy.

REFERENCES

The following web sites were referenced in providing information in this report:

1. FHWA Status of Retroreflectivity Standards Slides 22-26. Retrieved July 17, 2003 from http://www.fhwa.dot.gov/safety/fourthlevel/retrstat42202.htm

2. HIGHWAY TECHNET – The online highway technology resource. Featured Projects; Project TE-29. This page was accessed on October 28, 2003. http://www.library.unt.edu/gpo/OTA/featproj/fp_te29.html

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US DOT FHWA. 12 December 2002; Safety, Minimum Maintained Retroreflectivity Guidelines Status. Last accessed on October 28, 2003. (http://www.fhwa.dot.gov/safety/fourthlevel/retrost.htm)

US DOT FHWA. Safety; Retroreflectivity; Overview. Last accessed October 28, 2003. (http://www.fhwa.dot.gov/safety/fourthlevel/pro_res_retrore_over.htm)

APPENDIX A

EXCERPTS FROM 2000 MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES

The following is reference to the law mandating the MUTCD set a standard for a minimum level of retroreflectivity.

This section was copied from Page 3 of the MUTCD 2000 – Appendix A1 – Congressional Legislation:

> **Public Law 102-388-OCT. 6, 1992 (DEPARTMENT OF TRANSPORTATION AND RELATED AGENCIES APPROPRIATIONS ACT, 1993)**
>
> **Section 406 -** The Secretary of Transportation shall revise the Manual of Uniform Traffic Control Devices to include –
>
> > (a) a standard for a minimum level of retroreflectivity that must be maintained for pavement markings and signs, which shall apply to all roads open to public travel;
> >
> > (b) a standard to define the roads that must have a centerline or edge lines or both, provided that in setting such standard the Secretary shall consider the functional classification of roads, traffic volumes, and the number and width of lanes.
>
> http://mutcd.fhwa.dot.gov/pdfs/millennium/pr2/appr2.pdf Last accessed on November 6, 2003.

This section was copied from Page 17 of the MUTCD 2000 – Chapter 2A – General Provisions and Standards showing a standard for minimum retroreflectivity standards has not been established:

> **Section 2A.09 Minimum Retroreflectivity Levels**
>
> Support:
>
> (*This section is reserved for future text based on FHWA rulemaking.)*
>
> The above was copied from the following link:
> http://mutcd.fhwa.dot.gov/pdfs/millennium/06.14.01/2andi.pdf Last accessed on November 6, 2003.

From the Federal Register Online via GPO Access
http://www.gpoaccess.gov/fr/retrieve.html Last accessed on November 6, 2003.

The following sections were copied from the Federal Register / Vol. 65, No. 243 / Monday, December 18, 2000 / Rules and Regulations.

Page 78923:

DEPARTMENT OF TRANSPORTATION

Federal Highway Administration

23 CFR Part 655

[FHWA Docket Nos. 97-2295 (Formerly 96-47), 97-3032, 98-3644, 98-4720, 99-5704, 99-6298, 99-6575, and 99-6576] RIN 2125-AE11, AE25, AE38, AE50, AE58, AE66, AE71, and AE72

National Standards for Traffic Control Devices; Manual on Uniform Traffic Control Devices for Streets and Highways

AGENCY: Federal Highway Administration (FHWA), DOT.

ACTION: Final amendments to the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD).

SUMMARY: This document contains the complete revision to the MUTCD as adopted by the FHWA. The MUTCD is incorporated by reference in 23 CFR part 655, subpart F and recognized as the national standard for traffic control devices on all public roads. The new MUTCD has incorporated technological advances and application change, as well as improved the overall organization to clarify the discussion of the content.

DATES: The final rule is effective January 17, 2001. However, the FHWA is setting later compliance dates for some portions of the MUTCD; see the SUPPLEMENTARY INFORMATION section for further details. Incorporation by reference of the publication listed in the regulations is approved by the Director of the Federal Register as of January 17, 2001.

FOR FURTHER INFORMATION CONTACT: Mr. Ernest D. L. Huckaby, Office of Transportation Operations (HOTO-1), (202) 366-9064, Department of Transportation, Federal Highway Administration, 400 Seventh Street, SW., Room 3412, Washington, DC 20590. Office hours are from 7:45 a.m. to 4:15 p.m. E.T., Monday through Friday, except Federal holidays.

Page 78925:

16. In Section 2A.08 Illumination and Retroreflectivity, two tables are added (Table A.1 and 2A.2) to help clarify the text that used to be in Sections 2A.16, 2A.17, and 2A.18 of the 1988 MUTCD. The FHWA received no docket comments on this section. In the STANDARD statement, the requirement of sign retroreflectivity or illumination is extended to include guide signs. This requirement applies to all signs unless specifically stated otherwise in the MUTCD text for a particular sign or group of signs. The FHWA believes this will improve safety and visibility during adverse ambient conditions. There were no docket comments on this section.

Page 78928:

37. In Section 2B.35 Design of Parking, Standing, and Stopping Signs, the FHWA inadvertently omitted the proposed text, stating that all street parking signs are to be illuminated or retroreflective. This text is consistent with Section 2A.08 Illumination and Retroreflectivity, which discusses the general provisions and standards for signs. The FHWA believes the language that addresses retroreflectivity and illumination is best discussed as a STANDARD in Section 2B.01 Application of Regulatory Signs. The FHWA is adopting the following text: ``Regulatory signs shall be retroreflective or illuminated to show the same shape or similar color by both day and night, unless specifically stated otherwise in the MUTCD text discussion of a particular sign or group of signs (see Section 1A.08).

39. The 1988 MUTCD contained a sentence that the WALK ON LEFT (R9- 1) and NO HITCHHIKING (R9-4) signs do not have to be retroreflective. However, the FHWA is changing this and requiring that all signs, including these pedestrian signs, shall be either illuminated or retroreflective. The FHWA did not receive any comments opposed to this adopted change.

Page 78930:

61. In Section 2D.03 Color, Retroreflection, and Illumination, the STANDARD statement in paragraph 3 is modified to extend the general requirements for retroreflectivity and/or illumination to ``all'' guide sign messages and legends, unless specific exceptions are provided. This is consistent with Section 2A.08 which requires all signs to be retroreflective and/or illuminated. There were no docket comments on this section.

Page 78931:

69. In Section 2D.44 General Service Signs, paragraph 15 is changed to eliminate the term ``opaque background'' since all backgrounds shall be either retroreflective or illuminated as discussed in Section 2D.03. There were no docket comments on this section. In this same section, an OPTION is added to use the new word message sign ``ROAD CONDITION DIAL 511'' to notify road users of road and traffic conditions. This is a new OPTION that was not included in the NPA because at the time, it had not been approved by the Federal Communications Commission.

72. In Section 2E.05, a STANDARD sentence is added in paragraph 1 to provide that signs which are not illuminated must be retroreflective. Also in this section, paragraph 4 recommends that all overhead sign installations should be illuminated unless an engineering study shows that retroreflection alone will perform effectively. The FHWA did not receive any comments.

Pages 78938-78939:

138. In Section 3B.21 Curb Markings (referenced in the NPA as 3B.15), paragraph 5, the FHWA is adding paved median noses to the locations that should have retroreflective solid yellow markings. This addition is made in response to recommendations for older drivers \11\, which shows the benefits of having these additional markings. The FHWA received two comments which suggested that the text be changed to an OPTION, and one technical comment that suggested that additional guidance be included on the placement of the markings. The FHWA is adopting the text as proposed in the NPA because the FHWA believes that retroreflective markings should be placed to increase the visibility of

paved median noses. The FHWA also believes that the portion of the paved median nose that should be marked should be left to each jurisdiction's judgment.

Page 78944:

185. In Section 6E.03 Hand-Signaling Devices, the proposed statement ``When flashing lights are used at night, the illumination shall not blind drivers." was questioned by three commenters because there no acceptable measures to determine this. The FHWA agrees and has removed the statement from the second GUIDANCE of this section. In the second STANDARD the word ``red" was inadvertently left out of the NPA. The STANDARD now reads, ``When used at nighttime, flags shall be retroreflectorized red." This is identical wording to that in the 1988 Edition of MUTCD, Revision 3. This should have no impact on State or local governments since the FHWA is retaining the current requirements.

Page 78945:

195. In Section 6F.53 ARROW PANELS (referenced in the NPA as Section 6F.56), the FHWA is changing the first proposed SUPPORT statement in the NPA to a STANDARD as the statement is a definition and definitions are by their very nature STANDARDS. Additionally, since arrow panels are similar to portable changeable message signs, the FHWA is adding a GUIDANCE statement to Section 6F.53 identical to the GUIDANCE statement for locating and providing protection for portable changeable message signs. The GUIDANCE statement reads, ``An arrow panel should be placed on the shoulder of the roadway or, if practical, further from the traveled lane. It should be delineated with retroreflective temporary traffic control devices or when within the clear zone, shielded with a barrier or crash cushion. When an arrow panel is not being used, it should be removed; if not removed, shielded; or if the previously two options are not feasible, delineated with retroreflective temporary traffic control devices." This GUIDANCE will maintain traffic flow efficiency and improve safety.

Page 78947:

220. This amendment to Section 7E.04, paragraph 2, is based on a comment that the FHWA received indicating that mentioning ``daytime, nighttime, and twilight hours," and the reference to Section 6E.03 is redundant. The FWHA agrees and the reference to ``daytime, nighttime, and twilight hours" is deleted. The FHWA is also amending the text in the last paragraph of Section 7E.04 to include ``police officers" in addition to adult guards and student patrols in wearing high-visibility retroreflective material or clothing, since police officers may be used for crossing supervision as mentioned in Section 7E.06.

Page 78948:

226. In Section 8B.02 Highway-Rail Grade Crossing (Crossbuck) Sign (R15-1, R15-2), the FHWA has added a STANDARD statement (as proposed in the 1999 NPA) to require the placement of a strip of retroreflective white material on the back of each Crossbuck sign for the length of each blade, except where Crossbuck signs are installed back-to-back. The FHWA also added a STANDARD statement (as proposed in the 1999 NPA) to require the placement of a strip of retroreflective white material on the front and back of each Crossbuck support. The FHWA is providing a phase-in compliance period of 10 years for existing installations to minimize any potential impact to State and local highway agencies. This change takes effect immediately for all new installations.