IDAHO TRANSPORTATION DEPARTMENT
RESEARCH REPORT

RP 198

Market Research for Idaho Transportation Department Linear Referencing System (LRS)

By

Cambridge Systematics, Inc.

Prepared for

Idaho Transportation Department
Research Section,
Transportation Planning Division
http://itd.idaho.gov/planning/research/

August 31, 2009

final report

Market Research for Idaho Transportation Department Linear Referencing System (LRS)

prepared for

Idaho Transportation Department

prepared by

Cambridge Systematics, Inc.
100 Cambridge Park Drive, Suite 400
Cambridge, Massachusetts 02140

date

August 31, 2009

This document is disseminated under the sponsorship of the Idaho Transportation Department and the United States Department of Transportation in the interest of information exchange. The State of Idaho and the United States Government assume no liability of its contents or use thereof.

The contents of this report reflect the views of the author(s), who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official policies of the Idaho Transportation Department or the United States Department of Transportation.

The State of Idaho and the United States Government do not endorse products or manufacturers. Trademarks or manufacturers' names appear herein only because they are considered essential to the object of this document.

This report does not constitute a standard, specification, or regulation.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Market Research for Idaho Transportation Department Linear Referencing System (LRS)		5. Report Date 9/2/2009 6. Performing Organization Code
7. Author(s) Yushuang Zhou and Bruce Spear		8. Performing Organization Report No.
9. Performing Organization Name and Address Cambridge Systematics, Inc. 100 Cambridge Park Drive, Suite 400 Cambridge, Massachusetts 02140		10. Work Unit No. (TRAIS) 11. Contract or Grant No. RP – 198
12. Sponsoring Agency Name and Address Idaho Transportation Department P.O. Box 7129 Boise, ID 83707-1129		13. Type of Report and Period Covered Final Report June 2009 – August 2009 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

For over 30 years, the Idaho Transportation Department (ITD) has had an LRS called MACS (MilePoint And Coded Segment), which is being implemented on a mainframe using a COBOL/CICS platform. As ITD began embracing newer technologies and moving toward a more client-server based computing environment, it is becoming increasingly burdensome to access MACS. Initial studies have been conducted to review the needs for a new LRS system, including an *LRS Needs and Recommendations Study* in 2006. The scope of this research task (BP – 198) is to review the findings from the 2006 LRS study, and reevaluate the agency's needs for LRS and the extent to which commercially available LRS systems or the LRS systems being used for other states will satisfy these needs. Based on the review findings, strategies are proposed and recommendation is made regarding how ITD can incrementally move to a GIS-enabled LRS system and what would be the cost and benefit implications.

17. Key Word	18. Distribution Statement
Linear Reference System (LRS) Linear Reference Method (LRM) Commercial off-the-shelf (COTS) Geographic Information System (GIS) MilePoint And Coded Segment (MACS)	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Table of Contents

List of Tables

List of Figures

Executive Summary

For close to 30 years, the Idaho Transportation Department (ITD) has had an LRS called MACS (MilePoint And Coded Segment), implemented on a mainframe using a COBOL/CICS platform. During the 1970s and 1980s, such a solution made sense for ITD, as most applications that needed to reference locations along the transportation networks were implemented in the mainframe environment. As ITD began embracing newer technologies and moving toward a more client-server-based computing environment, linking to the mainframe became increasingly burdensome.

To help address the situation, ITD initiated this research project (RP – 198) to conduct a market research for LRS. The ITD LRS system was evaluated in 2006 by GeoDecisions, and a report titled *Location Referencing Recommendations Project: Needs and Recommendation* was completed and delivered to ITD. The scope of this task order is to review the findings from the 2006 Study, evaluate similar systems being implemented by other state Departments of Transportation (DOTs), and conduct research to determine if commercial Off-The-Shelf software will meet ITD's needs. Based on our study, a range of strategies and cost estimates will be developed to implementing and phasing in a new LRS. Our recommended strategies can assist decision-makings for department managers as they consider modifying existing systems and/or acquiring new automated systems for linear referencing.

Needs Analysis Results

The first task is to revisit the priority need list from the 2006 Recommendation report. The CS project team also interviewed 14 business areas within ITD, including the following business groups at ITD:

- All six District Offices;
- MACS System Manager;
- Aeronautics Division;
- Enterprise Technology Services;
- Planning Services;
- Public Transportation;
- Intermodal and Roadway Planning Groups;
- Highway Operations; and
- Highway Project Development.

As the result of the review and the interviews, all needs are identified as "Remains a priority," "Not a priority," or "May or may not be a priority requirement." Our research finding is that most needs items identified in the 2006 Study remain to be priority requirements, with only a few that should be moved to the nonpriority or maybe category. However, there are some disconnections between the needs and recommended implementation plan; therefore, the recommendations in the 2006 Study need to be revised.

DOT Case Studies and Vendor Review

The development of LRS continues to be a primary effort at DOTs across the nation. Individual states also have done similar studies to look into questions that are specifically interesting to the agency. For example, the Minnesota Department of Transportation completed a study in 2008 to learn more about how other DOTs are managing, and maintain their network and road inventory data via an LRS.

Having worked with many LRS systems for state DOTs throughout the country, Cambridge Systematics is highly knowledgeable of the best practice and critical success factors for LRS implementation. There are four major software packages and vendors that are commercially available for LRS management, including **ESRI**, **Intergraph**, **EXOR**, and **Bentley**. For each vendor, a phone interview was conducted to understand how each software implement LRS; how well does your software package potentially meet the ITD needs, mostly the need to support multiple LRMs; how their LRS can be compatible with ESRI products, which is the dominate GIS software currently in use by ITD; and what is the cost and pricing model for system acquisition, deployment, licensing and maintenance fees, and training. We also asked vendors about what other states have implemented LRS with its software. All vendors met the basic requirements of supporting multiple LRMs, and be compatible with ESRI products.

We also interviewed state DOTs that uses various LRS packages. For this research project, we did an initial scan of many state DOTs, including Alaska, California, Iowa, Maine, Minnesota, Montana, Nevada, Oregon, and Washington State. This initial list includes a mixture of states that are either regarded as best practices in LRS implementation, or states that are similar based on various criteria. Five state DOTs are selected as case studies, including **Washington**, **Montana**, **Nevada**, **Maine**, and **Alaska**, a mixture of states using different LRS software and in different stage of LRS implantation. Interviews were conducted with representatives from these five states to collect functional and cost information for their respective LRS system, the success story, the critical factors that contribute to the success, as well as lessons that can be learned by ITD. Table ES.1 shows a summary of interview results. Cost of system development varies significantly from state to state, with the lower number being below half a million (Maine DOT using Exor), and the upper number exceeding over 5 million (Nevada DOT using Intergraph).

Table ES.1 State DOT Interview Summary

DOT	System Migration Path	Project Cost	Lesson Learned
Washington State	Mainframe TRIPS + ESRI GIS.	No explicit cost figure. Most work conducted in house.	• Avoid too many cooks in the kitchen and encourage accountability. • Take an incremental and modular approach.
Montana	Mainframe HIS being moved to Oracle-based TIS in 1990s. Currently reevaluate software choice.	Not available.	• User buy-in is the No. 1 priority.
Nevada	Multilevel LRS (MLLRS) using Intergraph products. In the process of moving to ESRI platform.	> $5 million.	• Clean data first. • User buy-in. • Document the workflow. • Training and support. • Focus on the coordinate-based system.
Maine	In the 1990s moved from Mainframe to Oracle + ArcView. In 2002 decided to develop METRANS using Exor Highways.	$300,000 initial software acquisition cost + $25,000 annual maintenance cost.	• Get buy-in from other systems and users. • Move towards Route and Coordinate LRM. • Have your data cleaned up. • Do not leave the configuration task to selected vendor
Alaska	Mainframe HAS developed in 1970s. In 2005 started building a new LRS system using ArcSDE/ Oracle RDBMs	In the ballpark of $1 million.	• Stakeholder buy-in. • Incremental phases.

LRS Strategy Recommendations

Based on our research, we propose the following recommendations and road-map for implementing an updated LRS at ITD that will be compatible with current GIS technology, and will support agencywide database integration.

1. *Obtain Agencywide Buy-In*

It is important to understand the technical, institutional, and cultural issues related to data sharing and integration within the agency; and to note that a successful LRS system should be able to balance interests for all involved parties. In addition to the support and financial commitment from the executive-level decision-makers, it is important to obtain buy-ins from different departments and district offices, with all parties reaching consensus in principle to the concepts of LRS.

Though much of the initial groundwork for obtaining buy-in from key agency organizational units has already been undertaken various LRS market research tasks, further stakeholder meetings are recommended to solicit specific user's need for and use of LRS data. The project team has developed a business analysis framework for analyzing user needs, and the understanding the role of LRS in supporting agency business processes. Use cases are recommended as an approach to model the proposed functionality of a new system.

2. *Establish a Data Repository for ITD Geospatial Data*

The first phase of this task is to develop the system architecture and a logical database design for the relational database, which will provide the foundation for integration and distribution of data in many of ITD's business data systems. A centralized data repository/warehouse is recommended with the following geospatial data at a minimum:

- The official state roadway network database;
- Geospatial boundary files for political and administrative boundaries; and
- Other statewide geospatial databases as base map background.

3. *Develop/Acquire Procedures for Implementing a Route/Milepost LRM*

ITD should begin its development of a new LRS by building or purchasing a procedure that will enable it to locate and display linear and point features based on a location defined by ITD segment code, milepost, and offset. Initial development and testing of this procedure should be carried out using data from the current MACS linear datum. Also suggest proving an interactive or automatic method of creating the Milepost log book.

4. *Migrate MACS from mainframe to server-based RDBMS*

The MACS segment code and milepost LRS needs to be migrated from its current mainframe environment to a relational database management system operating in a client-server environment. The migrated MACS will become the first LRM in the new ITD LRS. The migration should take place so as not to disrupt current MACS operations. Two systems will run in parallel for a few months before the final switch from MACS to RDMBS. As part of the migration process, the MACS segment code and milepost linear datum should be separated from the peripheral attribute data, such as political and administrative boundaries, functional class, scenic byways, etc. The assumption is that these boundary layers are already available, or can be easily created.

5. *Demonstrate the Use of the Route/Milepost LRM for Integrating and Displaying Agency Databases in a GIS Environment*

The GIS staff should work with one or more ITD Divisions or Districts to identify and develop an application to demonstrate how the Route/Milepost LRM procedure can be used to GIS analysis. The primary objective is to help market the LRS to initially skeptical organizational units and staff, and to identify additional requirements for new functions, LRMs, and data from potential users.

6. *Develop/Acquire Procedures for Implementing Additional LRM Procedures*

Additional LRM procedures can be added to support the integration of other agency databases. Three potential candidates for inclusion in the LRS are Route/Coordinates, Route/Milepoint, and Project Stationing. With the incorporation of each new LRM, new applications should be developed to showcase the enhanced capabilities and additional agency databases that are now accessible through the LRS.

Cost Estimate and Benefit Analysis

The costs to migrate from the current mainframe-based MACS LRS to a GIS-based LRS operating in a client-server environment will potentially include several procurement actions, and considerable staff time for ITD, at the headquarters and in various district offices. The substantial cost items include overall project management, outreach and internal marketing activities, data clean-up, software and hardware purchase, database design and development, software enhancements and application development, training, as well as system maintenance. Table ES.2 provides the ballpark cost estimates for developing a GIS-enabled LRS system. The lower range estimate is $1.45 million, and the upper range is $3.55 million. Since no detailed function requirement analysis has been conducted for an LRS system, the estimates are mostly based on our experience and research results for building similar systems. Please note the cost estimates do not include any costs associated with clean-up or enhancing the locational accuracy of any programmatic or business database that is managed by an organizational unit other than the GIS/LRS division (e.g., crash records, road inventory, signs, etc.). For the purposes of this study, it is assumed that responsibility for the locational accuracy and integrity of these business databases remain with the organizational unit that currently maintains them.

Table ES.2 Ballpark Cost Estimates

Tasks		Low ($1,000k)	High ($1,000k)
1.	Project Management & Stakeholder Buy-In	150	250
2.	Data Cleanup	250	500
3.	Software Purchase	50	500
4.	Hardware Purchase	50	100
5.	Database Design and Development	200	500
6.1	Software Enhancement (Initial)	200	350
6.2	Application Development (5-year)	250	500
7.	Training	100	150
8.	System Maintenance	200	700
Total		1,450	3,550

In order to justify the heavy investment of building an LRS system, it is important to conduct an analysis for benefits, cost savings, and Return On Investment (ROI) achieved through the use of LRS system. Detailed ROI analysis is not feasible in this study because cost saving needs to be built upon a thorough understanding of the existing cost of LRS-related activities within ITD. MACS is centrally managed; therefore, it is easy to estimate the cost associated with MACS. However, different district offices and business areas are creating, editing, and managing locational data in various ways; and it is not possible to get a good estimate of cost saving without very detailed business analysis. Our recommendation is for ITD to perform a detailed ROI analysis before signing off the vast investment for any proposed LRS system. The Oregon Department of Transportation (ODOT) provides an excellent example as it is in the process of building an LRS that will be designed to replace their current highway inventory. The new LRS called TransInfo is budgeted at $5.2 million, including in-house staff resources, as well as a contract value of $3.2 million with Exor in partnership with Cambridge Systematics and TC Technology. ODOT conducted a detailed Cost and Benefit Analysis for implementing the proposed TransInfo system, including the actual cost of software and services as contracted, as well as a refinement of other project costs and benefits. Analysis shows that ODOT will likely see an ROI within five years after implementation. The ROI analysis concludes that the TransInfo project is both cost-effective and in line with ODOT goals. Therefore, the Project Team for ODOT recommends that the project move forward.

1.0 Introduction

For close to 30 years, the Idaho Transportation Department (ITD) has had a Linear Referencing System (LRS) called MACS (MilePoint And Coded Segment), implemented on a mainframe using a COBOL/CICS platform. During the 1970s and 1980s, such a solution made sense for ITD, as most applications that needed to reference locations along the transportation networks were implemented in the mainframe environment. As ITD began embracing newer technologies and moving toward a more client-server-based computing environment, linking to the mainframe became increasingly burdensome. The MACS system was evaluated in 2006 by GeoDecisions and a report titled *Location Referencing Recommendations Project: Needs and Recommendation* was completed and delivered to ITD. In addition, in the fall of 2009 Applied Pavement Technology, Inc. conducted a study to evaluate ITD needs for Maintenance And Pavement Management Systems (MAPS). The study ranked a consistent LRS as one of the needs with high priority.

The scope of this task order is to review the findings from the *2006 study*, evaluate LRS implemented by other state Departments of Transportation (DOTs), and conduct research to determine if commercial Off-The-Shelf (COTS) software will meet ITD's needs as outlined by the *2006 Needs and Recommendations Study*. The overall purpose of the project is to analyze the agency's needs for a new LRS system, and the extent to which commercially available software or LRS systems being used for other states will satisfy these needs. The information and recommendations developed under this project will assist department managers as they consider modifying existing systems, and/or acquiring new automated systems for linear referencing. This report presents key findings from these tasks, including information on the following:

- Key functional needs for the new LRS system;
- Best practice solutions implemented by other state DOTs in LRS development;
- Vendors that offer commercially available products that could fully or partially meet ITD's needs;
- A range of strategies for implementing and phasing in a new LRS; and
- Estimated costs to obtain LRS management tools and review the potential benefits.

2.0 Priority Need List Review and Recommendations

The first task was to review the *Location Referencing Recommendations Project: Needs and Recommendation*, which included a list of 22 priority needs for a new or enhanced LRS. This section revisits the priority need list, and makes recommendations based on our recent interviews with ITD organizational units on July 21 to 22, 2009 (See Appendix A for list of interviewed groups, and Appendix B for Interview Guide.). All needs are identified as "Remains a priority," "Not a priority" or "May or may not be a priority requirement."

(1) Comprehensive LRS Maintenance Environment

The new system must have one point of data entry that would update the LRS and related location referencing methods (LRMs), and then propagate the change to the business units (or notify the appropriate data maintainer(s)).

This remains a priority requirement. There should be a single organizational unit within ITD that is responsible for corrections and updates to the underlying linear datum to which all LRMs used by ITD are linked.

(2) LRM Transformation Engine

The new LRS must have the ability to translate or automatically transform a location described by one LRM to the same location described in another LRM. The system must accommodate single transactions and batch processes.

This remains a priority requirement. The primary purpose of an LRS is to serve as a translator between different LRMs. Ideally, users should be able to use the LRS without having to understand the translation process itself. For example, a user who locates a feature or event using a sign route and milepost should be able to obtain the latitude/longitude coordinates of that feature within a specified level of accuracy.

(3) Spatially Enabled Relational Database

The new LRS must allow all linear reference relationships and the geometry for the centerline to be stored in the same technical environment, a relational database management system (e.g., Oracle, Oracle Spatial, and ArcSDE).

This remains a priority requirement. A primary objective for ITD is to migrate the LRS from its current environment on a mainframe computer to a GIS client-server environment with a relational database that is more directly accessible to users throughout the agency.

(4) Support for Local Roads

The new LRS must provide support for including local roads (all-inclusive or state-funded). The scope of which roads to include should be a business decision, not a system limitation.

This is not a priority requirement. Although a new LRS should not prohibit inclusion of any type of road or linear path (e.g., trails, bikeways), none of the ITD organizational units that we interviewed identified an immediate need to locate data on local roads. Moreover, most data on local roads are typically located using either latitude/longitude coordinates; street name and address (in urban areas); or intersection, distance, and direction. GIS technology, combined with an accurately populated street database, can effectively handle most, if not all, of these locational translations. (See also Requirement 12).

(5) Segment Code and Milepost LRM

Most of ITD's current planning/inventory business data is located via the segment code and milepost LRM. This LRM must be supported by the new LRS. This method is critical to the success of ITD's data integration effort, and must support both point and linear event definitions.

This remains a priority requirement. Most of the districts and many of the headquarters divisions have extensive experience in using the segment code and milepost LRM. Even if this LRM is eventually replaced at some point in the future, it is essential that the new LRS must support the segment code and milepost LRM in order not to disrupt ongoing agency operations and data collection efforts.

(6) Named Route Support

The new LRS must support the ability to define a route/street traversal along the segments between intersections.

This is not a priority requirement. This was not brought up as a need item during any of the stakeholder interviews. Current GIS technology, combined with an accurately populated and well connected all streets database, can be used to locate a named route or street between intersecting cross streets.

(7) Concurrent Named Route Support

The new LRS must support multiple named routes for each segment of the road network. It is desired that the system support an unlimited number of route names per segment.

This may or may not be a priority requirement. Virtually all GIS and LRS systems allow a road segment to be associated with multiple identifiers (e.g., road name, multiple sign routes, etc.). The important issue is whether each route will have its own linear measure (e.g., will a given road segment be referenced as Milepoint 3.1 – 4.5 on U.S. 29, but referenced as Milepoint 7.5 – 8.9 on State Route 67?). Typical LRS implementations will assign distance measures to only one of the sign routes traversing a road segment, based on some order of priority (e.g., Interstates take precedence over U.S. routes, which take precedence of state routes, etc.). If ITD wants to be able to assign separate distance measures for each route that traverses a road segment, this capability will need to be incorporated into the LRS. States have different ways of handling this issue: some states treat all routes as continuous, and record milepoint information for each route on a shared alignment. Others identify a primary or key route, and only maintain milepoints for the key route on a shared roadway section. At this time, it is not clear to us which way would work better for ITD.

(8) Route and Coordinate LRM

The new LRS must support an LRM that accepts a route name and coordinate (lat/lon, state plane x/y, UTM x/y), and relates that location to the linear network. This method must support point and linear event definitions.

This remains a priority requirement. A key function of any GIS-based LRS is to relate features and data located using an LRM to a fixed location on a map, where features are positioned based on coordinates. Depending on the precision of the coordinate data and on the accuracy of the underlying geospatial road network, the location of a feature defined solely by coordinate values may not coincide with the correct road feature. Therefore, it is often necessary to also specify a road name or sign route so that the feature can be "snapped" to the appropriate road segment. An important requirement for ITD is the capability to "snap" features to a specific road segment based on one (or more) route designations.

(9) Scalability

The new LRS must be scalable so that new LRMs can be added as additional uses for the system are identified. For example, a linear stationing LRM may be needed in the future.

This remains a priority requirement. Scalability, or at least the flexibility to accommodate new LRMs without rebuilding the entire LRS, is a basic requirement for any LRS. Several of the ITD Districts specifically mentioned that they would like to be able to link project plans to the LRS and to other geospatial data using a GIS. However, it was not clear from the discussions whether the District staff want to use the GIS simply as a locational index for retrieving project plan documents, or whether they really want to integrate each project site plan as a geospatial object. In order to use the GIS as a location index, it does not necessary need a new LRM based on stationing, but merely to identify the locations of the base station markers to which project stationing measures are referenced. If the objective is to fully integrate project plans into a GIS environment, this is a much more complex problem that goes beyond LRS to fundamental issues dealing with geospatial data architecture. Many state DOTs are currently wrestling with this problem, but it should be addressed outside of the requirements for a new LRS.

(10) Support for Web Services

The new LRS must provide ITD with the ability to use provided web services (off-the-shelf), or to develop its own web services to support linear analysis and transformations.

This remains a priority requirement. A primary objective for ITD is to facilitate access to geospatial and linear referenced data throughout the agency. A web-based GIS is the most efficient way to provide displays of geospatial data, as well as basic geospatial analysis. An important issue here is how much analysis capability should be provided through web services. While basic transformations between linear referencing methods is certainly desirable as a web application, applications requiring intensive data analysis or complex queries can seriously impact web server performance, and should probably be limited to desktop applications.

(11) Route Milepoint LRM

The new LRS must support an LRM that accumulates distance from the beginning of the defined route. This method must support point and linear event definitions.

This remains a priority requirement. Even though ITD's current linear referencing method uses a modified reference post approach in which the milepost signs serve as physical reference posts along a designated route, Route Milepoint is a basic and widely used LRM, usually serving as the fundamental LRM to relate all other LRMs. For example, accumulated mileage to a reference milepost is required to identify the location of the reference point in the field. An advantage to using the milepoint method is that reference posts or signs do not have to be maintained in the field. However, the milepoint method requires field staff go back to the beginning of the route to start measuring distance in order to get a reference, and the field crew must know where the route begins and the primary direction of the route. Also, the Route Milepoint LRM can become increasingly inaccurate over time as a road is realigned and its geometry modified.

(12) Literal Description LRM

The new LRS must support an LRM that uses the route definitions to establish location by defining location by road names, cross streets, and offsets from cross streets (e.g., On Main Street, At 1st Avenue, 20 meters toward 2nd Avenue). This method must support point and linear event measures.

This may or may not be a priority requirement. Development of a literal description LRM requires a complex query handling capability, an accurate road name database, and a standardized road naming convention that must be applied to the database. For example, is Avenue abbreviated Av or Ave? Is First Street entered as First or 1st? This database must be maintained on a continuing basis in order to support the LRM. Given that most of the locations that would be defined using this LRM are local roads that are off the state system, ITD should determine if it is cost effective to maintain an all-roads database at the level of accuracy and completeness necessary to effectively utilize a literal description LRM.

(13) Current ITD GIS Compatibility

The new LRS must be compatible with ESRI, ArcGIS, ArcSDE, Oracle Spatial, and SQL Server technologies that are already in place at ITD.

This remains a priority requirement. ITD has already made a substantial investment in GIS and database management software that are capable of supporting many applications of LRS. Any LRS that is implemented at ITD should work within this current software environment and not require a change to new GIS or DBMS software. However, it may be necessary to develop new tailored software procedures or applications within this existing environment to fully implement a new LRS.

(14) Leveraging of ITD's Existing Data

The new LRS should take advantage of existing systems (data), and should be able to accommodate queries for historical data that use one of the previously mentioned LRMs. This need does not imply that the current data model be directly migrated, but that the information about road length and milepost distances could be used to populate a new LRS (should ITD desire to use that data).

This remains a priority requirement. At a minimum, the new LRS must be able to support ITD's current segment code and milepost LRM (see Requirement 5), as well as other locational referencing methods that are currently being used to display geographically referenced data. This does not mean, however, that all current and historical LRMs ever used by ITD need to be supported by the new LRS. Some historical databases that were locationally referenced using an outdated or overly complicated LRM (e.g., crash records containing a literal description of the location) may not require routine queries using a GIS, or could be converted to another LRM as needed. ITD should develop a prioritized list of agency databases based on their usefulness within a GIS and the level of effort required to locationally reference them.

(15) Documented Detailed Business Processes

The processes for data collection, integration, and presentation of the LRS data must exist to make certain of the availability of accurate, current, and timely data.

This may or may not be a priority requirement. For the establishment of an LRS, it is of critical importance to document how each agency database is collected, including the method used for locational referencing, its interdependency with other agency databases, and the primary agency business processes that it supports. However, for the purposes of defining a new LRS, it may be sufficient to simply identify what agency databases are essential for establishing a core GIS capability, and how data in each of those core databases are locationally referenced. This, combined with a requirement for system scalability (see

Requirement 9) to accommodate new databases as GIS use grows within the agency, may preclude the need for a comprehensive agency data study, at least initially.

(16) Documented Detailed Business Rules

The rules for proper use of the LRS and methods must exist to make certain of proper usage of the new system.

This remains a priority requirement. It is important that both database contributors and users of an agency GIS have access to information that enables them to understand available data sources, data content, and limitations on the accuracy of the data, including locational accuracy. Much of the information related to data content and quality is the responsibility of the organizational unit responsible for collecting, compiling, or updating each individual database. However, information on the LRMs and the locational accuracy of those methods should be documented by ITD unit responsible for developing and maintaining the LRS and GIS.

(17) Support for Web Applications

The new LRS must be compatible with web development architectures (preferably .NET) to allow ITD use of LRS functions in custom web applications.

This remains a priority requirement. This requirement is really an extension of Requirement 10. Given the rapid evolution of web-based software tools, an important consideration is that future web-based applications involving the LRS be developed using current industry practices and software tools.

(18) Temporality Support

The new LRS must support the query and integration of linear referenced business data that includes data relating to the date the event was current or the road was in service. These would be "real world dates," not system dates when the database was updated.

This may or may not be a priority requirement. Managing temporal changes for both individual data records and for the LRM used to locate the events or features described by the data is certainly a desirable function. However, responsibility for including temporal stamps for specific data records rests with the organizational unit responsible for collecting each database. Many ITD databases do not currently include temporal stamps, and relatively few of the organizational units we interviewed indicated that analysis of historical data was a high priority in carrying out their mission. While it may be appropriate for the LRS to support temporal queries, particularly when they involve changes in the underlying locational reference (e.g., historic crash data that includes records of crashes that occurred on road segments that have been realigned or re-signed), the maintenance of a temporal linear datum is labor intensive, and ITD may want to evaluate whether this temporal support capability is currently used, or would likely be used in the near future.

(19) Network Traversals

The new LRS must include the ability to define user-specified traversals throughout the network to facilitate traffic and speed studies for congestion analysis.

This is not a priority requirement. The ability to define user-specified routes and relate these routes to an underlying road network are functions typically provided through GIS software tools rather than an LRS.

(20) Maintenance of LRS Integrity During Transaction

The new LRS maintenance environment must maintain the stability and integrity of the production LRS during a change to the linear referencing network. As new roads are added, several small transactions may be required to make the update; these small transactions may leave the linear referencing network in a state of instability. The final implemented system (through technologies or processes) must leave the production linear network stable at all times.

This may or may not be a priority requirement. While it is certainly important to maintain the integrity of the LRS to support agency users, there is no reason that updates to either the road database or the LRS must be conducted dynamically on the production system. It is much more likely that updates would be conducted off-line on a back-up copy of the production database, allowing quality assurance and quality control (QA/QC) testing and analysis to be carried out without affecting the production system. After testing, the updated copy of the database could be uploaded to the production server during a system downtime. This requirement appears to be more related to LRS maintenance procedures than to the design of the new LRS.

(21) System Dates

The new LRS must be able to track the dates of changes to the database. These are often different than the real-world dates, but are important for tracking the history of updates to the LRS data.

This may or may not be a priority requirement. While it is certainly desirable to maintain a documented record of updates and corrections to the underlying road network and LRS, this can be done relatively easily with time stamping of database records. However, it is important for ITD to determine the criteria for initiating a new time stamp on data records, whether old records will be retained in the database, and whether procedures will be developed for recreating databases based on time stamps. For example, should a new database record be created whenever a change is made to any attribute value in the database? Should the old data record be retained, even if the change was to correct a simple data error (e.g., a typo in a road name)? Should any user be able to recreate a database for any date? Who would use such a capability, and how important is this capability? While creating the functional capability within the GIS and LRS to track changes and updates is relatively straightforward, actually maintaining the staff discipline to record all updates and managing a constantly growing database containing obsolete data records may not be cost effective.

(22) Different Centerline Representations

The new LRS should be flexible enough to handle different abstractions of the road centerline (e.g., single centerline versus separate traveled way centerlines on divided roadways). It is preferred that multiple centerline representation could be assigned to any linear extent of roadway versus a single geometric description.

This is not a priority requirement. The translation of an LRS across different representations of a road centerline depends more on how the road database is designed than on the LRS. In our interviews with ITD organization units, one group expressed an interest in having a less detailed representation of the road network (e.g., single centerline, no interchange ramps), but did not identify a critical application need at this time. An important consideration in the overall design of a new LRS is whether each side of a divided highway is represented separately in the LRS (i.e., is road inventory and other agency data collected and stored for one or both directions?) Many states establish their LRS and collect data only for a specified “inventory direction.” This greatly simplifies data display and use of a simplified single centerline abstraction of the road network, but essentially leaves the noninventory road feature with little or no attribute data. Alternatively, road data may be collected in both directions using separate linear routes. This allows for more accurate location of roadway features (e.g., signs, culverts, crashes), but requires additional internal procedures to summarize the data when using a single centerline representation of the road network.

3.0 State DOT Case Studies

Using a common frame of location as a reference, GIS provides a framework for collaboration and communication within and between agencies. A lot of studies and research have been conducted over the years on the topic of LRS for state transportation agencies. The Transportation Research Board (TRB) compiled a synthesis of *Highway Location Referencing Methods* (National Cooperative Highway Research Program (NCHRP) Synthesis Report No. 21) as early as 1974. The recently published report for the NCHRP 08-36 Task 80 (*Synthesis of State Practices in Developing Linear Referencing Systems*) conducted an inventory of LRS-related activities at state DOTs, including five case studies. The development of LRS continues to be a primary effort at DOTs across the nation. Individual states also have done similar studies to look into questions that are specifically interesting to the agency. For example, the Minnesota DOT completed a study in 2008 to learn more about how other DOTs are managing and maintaining their network and road inventory data via an LRS.

For this research project, we did an initial scan of nine state DOTs, including Alaska, California, Iowa, Maine, Minnesota, Montana, Nevada, Oregon, and Washington State. This initial list include a mixture of states that are either regarded as best practices in LRS implementation; or states that are similar based on various criteria, such as: 1) overall business context for the LRS (i.e., is it implemented as part of an agencywide enterprise GIS, or just for a few functional business systems?); 2) experience in migrating away from a legacy system; 3) major technical barriers encountered (e.g., locating reference points, handling shared and divided routes, updating procedures, etc.); and 4) resource requirements for both LRS development and ongoing maintenance (size and extent of the reference network, rural vs. urban, etc.).

After the initial review, five state DOTs were selected as case studies for this research project, including Washington State, Montana, Nevada, Maine, and Alaska, a mixture of states using different LRS software. Interviews were conducted with representatives from these five states to collect information, such as the following:

- Software/system the DOT is using for linear referencing. What other software the DOT evaluated and considered? Why did the DOT choose the current LRS system?
- The path of developing the LRS. How did the DOT get where it is now?
- Benefits, cost savings, and return on investment achieved through the use of the LRS system. Cost includes items such as initial software acquisition and licensing, data collection, system design, system development, maintenance, and training.

- The success story, the critical factors that contribute to the success, and lessons that can be learned by ITD.
- Any other comments/advice/suggestion related to building an LRS system.

Table ES.1 shows a summary of key results from State DOT interviews. Please note that case study summaries show the views expressed by state DOT representatives whom we interviewed. It does not necessarily represent the views of everybody within the same DOT, or the views of Cambridge Systematics.

Table ES.1 State DOT Interview Summary

DOT	System Migration Path	Project Cost	Lesson Learned
Washington State	Mainframe TRIPS + ESRI GIS.	No explicit cost figure. Most work conducted in house.	• Avoid too many cooks in the kitchen and encourage accountability. • Take an incremental and modular approach.
Montana	Mainframe HIS being moved to Oracle-based TIS in 1990s. Currently reevaluate software choice.	Not available.	• User buy-in is the No. 1 priority.
Nevada	Multilevel LRS (MLLRS) using Intergraph products. In the process of moving to ESRI platform.	> $5 million.	• Clean data first. • User buy-in. • Document the workflow. • Training and support. • Focus on the coordinate-based system.
Maine	In the 1990s moved from Mainframe to Oracle + ArcView. In 2002 decided to develop METRANS using Exor Highways.	$300,000 initial software acquisition cost + $25,000 annual maintenance cost.	• Get buy-in from other systems and users. • Move towards Route and Coordinate LRM. • Have your data cleaned up. • Do not leave the configuration task to selected vendor
Alaska	Mainframe HAS developed in 1970s. In 2005 started building a new LRS system using ArcSDE/ Oracle RDBMs	In the ballpark of $1 million.	• Stakeholder buy-in. • Incremental phases.

3.1 WASHINGTON STATE

The Washington State Department of Transportation (WSDOT) stores and reports linear referencing-related activities in a system called Transportation Information and Planning System (TRIPS), a mainframe system developed using ADABAS in the mid-1980s. TRIPS serves crash, maintenance, pavement, traffic, signs, and accounting data needs. The GIS representations of roadways are stored outside the mainframe. There are two LRSs used at WSDOT: a DMI LRS and Spatial LRS. Both are described in more detail below.

DMI LRS

WSDOT has established and maintains a Distance Measuring Instrument (DMI)[1] LRS on all state highways. The DMI LRS was created by driving state highways with a vehicle-mounted DMI, a high-accuracy odometer. The DMI is set to zero at the beginning of the route; and calibrated against fixed points along the highway, such as bridge seats and intersections. Static features along the route are measured with the DMI. These features are recorded in the TRIPS database, and reported in the State Highway Log. The DMI LRS is only collected in one direction of travel; typically northbound and eastbound. The southbound and westbound data is referenced from the northbound and eastbound mile posting. The calibrated features from the DMI are also used to calibrate the spatial LRSs described below.

Spatial LRS

A spatial LRS is a representation of linear elements by planar (X, Y) coordinates in relationship to the earth's surface. It is used for spatial reference in a GIS. The GIS uses dynamic segmentation technology to locate points and segments along the state highways. WSDOT has three different spatial LRSs that have evolved over time to increase the horizontal accuracy and level of detail: the 500k, the 24k, and the recently completed GPS/LRS. WSDOT uses a State Route Mile Post (SRMP) method and an Accumulate Route Mileage (ARM) method to identify locations on state roads. Both SRMP and ARM methods have been implemented in GIS. The LRS uses an expanded SR number so that ramps, couplets, frontage roads, and other nonmainline features can be uniquely identified.

Changes in TRIPS need to be made in the GIS. Manual processes have been developed to link mainframe linear referencing data to the GIS. But it is a very cumbersome process to synchronize the changes. WSDOT is currently

[1]http://www.wsdot.wa.gov/mapsdata/tdo/PDF_and_ZIP_Files/DMILRS_Document.pdf.

conducting an internal study to review whether this is the best way to manage its LRS.

Over the years, WSDOT has made various attempts to replace its mainframe LRS system. However, due to funding constraints, WSDOT has been stuck with this fragmented and dispersed system. An in-house application has been developed to convert between different LRMs. However, the original developer of the application has left WSDOT, and the application has become a "blackbox" for the WSDOT staff. WSDOT is currently in the process of looking at alternative solutions to better meet their changing business needs[2]. It is investigating the idea of replacing their LRS with Global Position System (GPS)-based coordinates as the primarily location reference.

WSDOT has developed two other GIS applications that are related to it LRS: 1) MADDOG (which is now called the Workbench), an LRS-based GIS application that makes it easier to link data to the LRS; and 2) TransMapper, an ArcGIS explorer-based lightweight GIS application to link data to the LRS. Various other LRS data-related toolkits have been built over the years, mostly using internal staff resources.

WSDOT originally used Intergraph GIS, but eight to nine years ago the agency decided to switch to ESRI as its main GIS platform. Most of the LRS-related activities are conducted using internal staff resources. As the result, WSDOT was not able to put a price tag on its LRS development cost. But it reports that there are 12 to 15 full-time GIS staff and 1 person in charge of the changes in TRIPS.

Lessons Learned and Recommendations from WSDOT

1. Find somebody who is familiar with LRS, and understands how the system works and how it should work. Give that person the overall responsibility for managing the system. Avoid too many cooks in the kitchen, and encourage accountability.
2. Take an incremental and modular approach. Show success with a few elements and expand the system.

[2] Minnesota Department of Transportation Summary Results from A Survey of State Linear Referencing Practices, April 2008.

WSDOT Contact Person:

Ron Cihon
GIS Manager
P.O. Box 47384
818 79th Avenue SE, Suite B
Olympia, WA 98504-7384
Telephone: (360) 596-8920
Fax: (360) 596-8905
E-mail: cihonr@wsdot.wa.gov

3.2 MONTANA

The Montana Department of Transportation (MDT) used to have its LRS-based Highway Information System (HIS) on a mainframe. Over the years, its LRS system has evolved from the mainframe to the relational database world. In summary, here is the migration path for MDT:

- In the early 1990s, MDT migrated Roadlog away from the mainframe. Roadlog used to be the textual output of the mainframe system that provides the factual information of the state roadway system. The Roadlog database stores uniformly attributed segments derived from dynamically segmented transportation data that are broken at key attribute changes. New route log is created on a regular cycle to provide a segmented view of the data for the end-users. There was no GIS interface integrated into the Roadlog. Spatial reference was provided by post-processing.
- In 1997 MDT built the Transportation Information System (TIS), which evolved from the mainframe HIS. TIS is stored in an Oracle relational database environment, with a combination of the LRS and related attributes in one system. TIS houses much of the LRS-related data, and is the storage facility for many of Montana's roadway characteristics. TIS is not linked to the 3D spatial location.
- Currently, MDT is evaluating the update of this TIS system using the newer spatial capabilities of the databases and GIS software on the market, with the primary goal of improving the use and integration of road inventory and incident data throughout MDT.

The migration of Roadlog took about two to three years; mostly using internal resources within MDT. During the migration, the mainframe and the Oracle relational database system ran in parallel for a few months. The MDT person, who used to be in charge of the mainframe system, played an instrumental role in the migration task to move away from the mainframe, and to build the relational database. Building the Oracle relational database was another two- to three-year project with inputs from five to six application analysts at MDT. Detailed cost information for each of the projects was not discussed in the interview. Benefits and Return on Investment were not calculated at MDT.

Lessons Learned and Recommendations from MDT

1. **User buy-in.** If the approach is not backed up by users, the project is bound to fail. MDT has hired consultants to do a user needs assessment, a year-long project aiming to get the buy-in from various business units within the department, meeting with every division down to the bureau level. One can resolve and manage technical issues by setting aside budget, and you cannot solve perceptional issues if users are not on board.

MDT Contact Person:

Skip Nyberg
Program Analyst
Snyberg@mt.gov

3.3 NEVADA

Nevada Department of Transportation (NDOT) has developed an LRS system called Multi-Level LRS (MLLRS) based on the Intergraph GIS product. It is a statewide, multiagency database that supports all public roads in the State of Nevada. NDOT invested more than $5 million in the Intergraph solution; not including a lot of the hidden costs such as data cleaning. However, NDOT is currently in the process of moving away from Intergraph to an ESRI-based LRS system. The MLLRS is quoted to be an "85 percent (or so) solution." The software part has been most difficult for the migration process. Most data has been moved to ESRI, except for safety, which will continue to operate in the Intergraph software environment. The main reasons for the switch is that the Intergraph-based MLLRS is not user-friendly, overly complicated, and inflexible, as well as being entirely software vendor specific. NDOT views Intergraph as having a diminishing role in the state DOT GIS market over the years. It has been very hard to get continued training and support from Intergraph. Since most universities teach ESRI products nowadays, but not many graduates know how to use Intergraph products, it has been much easier for NDOT to find people with ESRI training background.

In terms of LRM, NDOT is planning on moving towards a coordinate-based location referencing system. For point locations, use X/Y coordinates directly. For linear locations, use linear referencing to get the location of the linear features, and then convert the starting and ending point locations to X/Y coordinates.

NDOT has undertaken a special project to show historic routes and look at what roads used to look like. This information is important for business areas, such as right-of-way and safety planning. Historic data can provide important information, such as what the DOT does and does not own, or allowing for spatial search for contracts, or look into crash history on certain roads.

Lessons Learned and Recommendations from NDOT

1. **Clean data first**. In order to build a LRS system, it is important to have a good road network. NDOT GIS has been working with the road inventory group to collect the transportation line work and feature inventory using videolog. NDOT has a three-tiered approach for collecting and managing its line work: 1) state-owned and maintained, 2) higher functional class roads, 3) other roads. There were a lot of inventory questions that have been resolved by cleaning up data. Issues such as inconsistent road names (e.g., US6, U.S. 6, U.S. 006) need to be addressed before the implementation of LRS. NDOT strongly suggested cleaning data first before building an LRS.
2. **User buy-in**. There is typically a lot of resistance to change within an organization. It is critical to find a group that wants to embrace the LRS concept, find the elements that prove to work, and then expand the elements to build a full blown system.
3. **Document the workflow**. Clearly understand how database systems are connected or related, and what the results should be when user pushes a button.
4. **Make sure training and support is available for users**. This is one of the main problems with their Intergraph system.
5. **Focus on the coordinate-based system**. Much focus is placed on linear referencing when it is not always the correct solution to some problems. NDOT suggested ITD to review the example of Texas DOT,[3] which is mainly a coordinate-based location system, with a temporal component.

NDOT Contact Info:

Eric Warmath
GIS Manager
Nevada Department of Transportation (NDOT)
1263 S. Stewart Street
Carson City, NV 89712
Telephone: (775) 888-7265
Fax: (775) 888-7203
E-mail: ewarmath@dot.state.nv.us

[3] The Texas DOT manages roadway locations and attributes with a commercial off-the-shelf ESRI system that has been in use for approximately 10 years. The system has 15 editors and thousands of users. If ITD decides to implement the Route/Coordinate LRM, follow-up discussion with Texas DOT is recommended.

3.4 MAINE

In the mid-1970s, the Maine Department of Transportation (MDOT) developed a mainframe system with asset and crash data. In the 1990s, MDOT decided to move away from the mainframe system to a GIS-enabled data warehouse. In 1999 MDOT built an Oracle BI Query system that was loosely integrated with ArcView 3.x. However, processing in the system was so burdensome (more than 24 hours for data processing) that MDOT decided to rebuild the system using modern GIS technology. In 2002 MDOT evaluated the various LRS systems, including Oracle, ESRI, EXOR, and Intergraph. The following four key requirements for the evaluation were:

1. Support link-node-based data with a route structure;
2. Support multiple LRMs;
3. Leverage existing GIS resources; and
4. Major systems built in Oracle.

The EXOR product Highways™ was selected because it met all the above key requirements. MDOT developed the Maine Transportation Network Solution (METRANS), a road inventory and network maintenance information system to address MDOT's linear referencing management needs. The datasets available in METRANS include information for highway inventory, traffic data, pavement management data, crashes, rail crossings, project history, and bridges.

EXOR was the best decision at the time for MDOT in order to meet all the key requirements. However, MDOT staff feels that the market place for LRS has changed. The Highways™ by EXOR has been evolving slower than MDOT would like to see. Reported issues and challenges include the following:

- MDOT has been stuck with old versions of ESRI GIS products because of compatibility issues with Highways™ by EXOR. Currently, MDOT is still using ArcGIS 9.1. EXOR upgrades come at least one year behind ESRI product. MDOT staff estimated that more than half of the upgrade problems with METRANS are on the GIS side.
- EXOR generally releases an upgrade every 6 to 12 months. There are also ongoing fixes (on average, two fixes per week). EXOR customers can use E-Credit that allows for certain customization. However, MDOT staff noted that E-Credit is also required for basic requests, such as documentation and upgrades.
- MDOT licenses Highways™ by EXOR by modules. With only six to seven users and a license for only the network manager module of Highways™ by EXOR, MDOT is one of the smaller clients for EXOR. Being a small fish in a big pond, MDOT feels that they have little influence on the vendor.
- A data warehouse was built and synchronized with data in METRANS. MDOT wants to have access to the live data in METRANS rather than the less

dynamic data in the data warehouse; however, access privileges cannot be granted to MDOT unless they sign up for a CPU license, which costs about $250,000 per license. MDOT is currently conducting research on how to change the data warehouse so that data can be extracted and used dynamically.

The METRANS project took 14 months to develop and cost $300,000, which includes the cost for license, setting up the database, configuration, meetings, and education process. After the initial system deployment, there is an annual maintenance charge of $16,000, which has now increased to $25,000. MDOT staff also spent a significant amount of time in managing and maintaining the system, including Information Technology (IT) resources required for the initial install and ongoing maintenance of EXOR's product. This initially required considerable time from an Oracle Database Administrator and Systems Analyst. It also requires about 25 percent of the Systems Analyst's time to troubleshoot issues associated with the LRS (much of this time to load updates into the data warehouse).

Lessons Learned and Recommendations from MDOT

1. Get buy-in from other systems and users.
2. Move towards Route and Coordinate LRM.
3. Have your data cleaned up. Data interpretation would be a challenge if data are not cleaned up or in synch.
4. During initial implementation, consider having extremely knowledgeable EXOR staff on site, perhaps for extended periods of time; but do not leave the configuration task to EXOR or any selected vendor.
5. The MDOT legacy mainframe system supported Node Offset as a linear reference method. But EXOR's product does not support either Node Offset or node attributes. This was one of the drawbacks of EXOR that MDOT accepted. ITD needs to be aware of the limitation.

MDOT Contact Info:

Nate Kane
GIS Manager
Maine DOT
16 Statehouse Station
Augusta, ME 04333-0016
207-624-3297, 207-624-3301(fax)
nate.kane@maine.gov

3.5 Alaska

Alaska's Department of Transportation and Public Facilities (ADOT&PF) has a legacy transportation database call the Highway Analysis System (HAS). ROADLOG is the basic building block of HAS; it defines the highway network structure and contains information about highway attributes (e.g., functional classification, maintenance responsibility, etc.) and inventory features (e.g., cross-streets, railroad crossings, bridges, schools, etc.). The LRS provided by ROADLOG is based on routes and route milepoints; features are assigned a milepoint, or milepoint range, on a particular route.

ADOT&PF is in the process of migrating away from HAS by developing an Enterprise GIS system. The overall project is called the HAS-GIS Interface project, and is being implemented using an incremental phased approach. At the heart of the HAS-GIS Interface is an enterprise Geodatabase that was designed to store and manage road centerlines and the transportation data (e.g., route attributes, accident data, and traffic data) from HAS in a GIS environment. The primary objective is to provide an integrated approach to the collection, storage, maintenance, and distribution of road-related data.

The design of the LRS-based Geodatabase was based on an understanding of the business processes to be supported by the HAS-GIS Interface Project. Extensive user needs and requirement analysis were conducted to analyze the GIS and LRS needs of ADOT&PF's Highway Database Management and GIS Mapping sections. Since the original data model design was completed in 2005, ADOT&PF has been building the network and populating the geodatabase using GPS and videolog data. Some elements in the data model have been changed since its initial implementation and ongoing modification are taking place as needed. But the core design of the data model remains the same; that is, to use GIS to manage the spatial data and the LRS. ESRI technology (ArcSDE, ArcGIS, and ArcGIS Server) was used for the implementation of the new LRS system.

Two types of GIS applications are being developed in order to support the geodatabase management and data analysis, including desktop GIS database maintenance application tools for the GIS staff, who will be managing the network centerlines, the geodatabase, and the linear referencing system for the geodatabase; and web-based view applications for geodatabase end-users, who have little or no familiarity with GIS, but need to have access to data stored in the geodatabase.

Lessons Learned and Recommendations from MDOT

1. Stakeholder buy-in is a key. Define one vision and stick to the vision. Adjust the vision as necessary when technology or institutional changes (such as funding situation) are needed. Make sure stakeholders are on board.
2. Build incremental steps. Each step needs to show tangible results. Do not take on too much, too fast.

ADOT&PF Contact Info:

Kerry Kirkpatrick
GIS Manager
Alaska Department of Transportation & Public Facility
3132 Channel Drive, Suite 200
Juneau, AK 99801
E-mail: kerry_kirkpatrick@dot.state.ak.us

4.0 Potential Vendors

According to the most recent GIS-T survey, four GIS software vendors – ESRI, Intergraph, Caliper, and Bentley – appear to dominate the GIS market among state DOTs. ESRI software products were reported in use in 90 percent of the state DOTs, while Intergraph, Bentley, and Caliper GIS software can each be found in about one-half of the state DOTs. Over 80 percent of the state DOTs use GIS software from at least two of the major vendors, and nearly one-half (44 percent) report having software packages from three or more different vendors. Development and use of GIS interoperability standards by the software vendors have significantly reduced many of the technical problems associated with sharing geospatial data between different GIS software.

The major software packages and vendors that are commercially available for LRS management include ESRI, Intergraph, EXOR, and Bentley. For each vendor, a phone interview was conducted with the following general questions:

- How does your software package implement linear referencing within its specific software?
- How well does your software package potentially meet the ITD needs? (Develop a matrix to compare each software package regarding its ability to meet the recommendations in the Needs and Recommendation study.)
- ITD mainly uses ESRI software to support their general GIS needs. How compatible is your software package with ESRI products?
- Provide information regarding the costs for system acquisition, deployment, licensing and maintenance fees, and training?
- What other states have implemented LRS with your software?

Table 4.1 is a quick overview of each of information provided by each vendor, including vendor name, LRS product name, whether the LRS product support multiple LRMs, license cost, and example state DOTs that have been implementing the particular vendor's technology. Appendix C provides more detailed response from vendors and their software packages.

Table 4.1 LRS Software Vendors

Vendor	Contact	Software	Support Multiple LRM?	License Cost	State DOT Clients
Bentley	Wendell Gardner Bellevue, WA 98008 Voice: 425-458-5210 Cell: 425-503-3843 Wendell.Gardner@bentley.com http://www.bentley.com	Location Data Manager Express (LDMx)	Yes	1st Processor: List Price Purchase: $15,000 each Annual Maintenance: $3,000 each 2nd and subsequent Processors: List Price Purchase: $10,000 each Annual Maintenance: $2,000 each	Iowa
ESRI	Terry Bills 380 New York St. Redlands, CA 92373 909-793-2853 ext 13313 tbills@esri.com www.esri.com	Transportation Solution as an addition to ArcGIS Desktop Solution; can be configured to run in a server application	Yes	The cost of the Transportation Solution for handling LRS is $5,000 per seat.	Many state DOTS
Exor	Russell Page 8310 South Valley Highway, 3rd Floor Englewood, Colorado 80112 303-524-1510 rpage@exorcorp.com	Highways	Yes	Pricing model varies. Refer to ODOT for software pricing structure. For ODOT, the software purchase price is $322.8K with annual maintenance fee of $102.2K for five years.	Oregon
Intergraph	Renee Barba 61 Inverness Dr East #102 Englewood, CO 80112 916 872-7625 renee.barba@intergraph.com www.intergraph.com	Geomedia	Yes	Geomedia Professional: $9,434 Transportation Manager: $7,632 Transaction Manager: $5,088 Geomedia Fusion: $9,540 Note: Prices listed are per seat.	

5.0 Recommendations and Strategies for Implementing a New LRS

Based on our interviews with key staff at ITD, our evaluation of recommendations made in the 2006 *Location Referencing System Needs and Recommendations Study*, and our case study reviews of other state DOTs, we propose the following recommendations and roadmap for implementing a updated LRS at ITD that will be compatible with current GIS technology, and will support agencywide database integration.

5.1 Obtain Agencywide Buy-In

A critical first step in the process of developing a system that requires coordination and participation of multiple organizational units is to ensure buy-in from key units. While it is unlikely that everyone will agree to all aspects of the plan (given the strong and differing positions encountered during the interviews), it is important that buy-in be obtained initially from certain key units or individuals, and that other units agree to at least adopt a wait-and-see approach rather than outright opposition. Key units include the following:

- ITD executive management (project funding support);
- Enterprise Technology Services (coordination of procurements for MAPS and development of an enterprise data warehouse);
- Current LRS/GIS staff (implementation and promotion of new LRS);
- At least one unit with responsibility for maintaining a major agencywide database (e.g., HPMS, MACS ROSE, crash data, sign inventory); and
- At least one District that is willing to champion the development of an LRS.

One of the key predictors of a successful LRS development and deployment is the level of support and financial commitment from the executive-level decision-makers in the agency (and possibly in the State as a whole) to provide and maintain the budgetary momentum for carrying out the LRS migration plan.

Success also requires better education and communication across different departments and District offices on the use and advantages of an agencywide LRS. It is important to understand the technical, institutional, and cultural issues related to data sharing and integration within the agency, and to note that a successful LRS system should be able to balance interests for all involved parties. Each business unit is unique with its own culture, business processes, methodologies, and GIS-related processes. "Buy-in" means agreement in principle to the following concepts:

- The ITD LRS needs to be migrated from a mainframe to a relational database management system operating in a client-server environment;
- The LRS needs to be compatible with geospatial representations of the road network (i.e., one should be able to display any linear referenced point or line segment using a GIS);
- The LRS needs to continue to support ITD's current route/milepost linear referencing method, as well as other location methods that are now used within the agency (e.g., geographic coordinates);
- The LRS needs to be an integral component of any enterprise data warehouse and data integration project; and
- Current ITD databases should not be required to change their current location referencing method.

In order to develop and sustain a successful LRS system, it is absolutely necessary to involve stakeholders from the start of the project. Stakeholder interviews can help to obtain a clear understanding of the GIS system from the user and business process perspective; they also offer an opportunity for the stakeholders to articulate their information needs and data flow issues, and understand the benefits of an LRS in modern GIS environment. Much of the initial groundwork for obtaining buy-in from key agency organizational units has already been undertaken through the *2006 Needs and Recommendations Study* and this LRS market research task. Further stakeholder meetings should solicit specific answers to the "what," "how," "where," and "who" aspects of user's need for and use of LRS data. Thus, *what* data are needed by different stakeholders? *How* do they want to use the data? *Where* are these data currently stored? *Who* is managing the data they need, and *who* is interested in using the data? Also, *when* do they need the data? The answers to these questions are influenced by many factors, such as ITD's budget cycles, policies and procedures, etc. Figure 5.1 shows the business analysis framework for analyzing user needs and understanding the role of LRS in supporting agency business processes. It summarizes the steps in this business analysis framework approach; the highlighted arrows show the flow of the project. The next step will be to use this framework to drill down to the next level for each of the stakeholder groups/business areas that were interviewed. The goal is to determine precisely and in sufficient detail what the business needs are for data, functions, networks/communications, and people.

Figure 5.1 LRS Business Analysis Framework

	DATA "WHAT"	FUNCTION "HOW"	NETWORK "WHERE"	PEOPLE "WHO"
STAKEHOLDER INTERVIEWS *Interviews*	List of data items important to the business	List of business processes	List of business locations	List of organizational issues important to the business
USER NEEDS/ REQUIREMENTS *Conceptual*		Business Process Model	Business Logistics System	Workflow Model
DATA MODELING/ APPLICATION DESIGN *Logical*		Data/Applications Architecture	Distributed Systems Architecture	
DATABASE/ APPLICATION DEVELOPMENT *Physical*			Systems Architecture	

Next steps in the buy-in process include presentations to senior management, followed by presentations or discussions with key stakeholders, describing the proposed LRS transition process, and addressing stakeholder questions and concerns. Our recommendation is to develop use cases, an approach that models the proposed functionality of a new system, to define the business process, understand user needs, and determine functional requirements of the key business areas. Use cases, which are more often thought of in the context of software engineering, can provide an invaluable tool to help users clearly visualize and understand the data flow and business process of the LRS system. In addition, ITD GIS department has developed a prototype ArcGIS server application that demonstrates how location data can be translated between ITD's segment code Milepost LRS and geographic coordinates can serve as the first visual example to many potential stakeholders of what a GIS-based LRS can do.

5.2 ESTABLISH A DATA REPOSITORY FOR ITD GEOSPATIAL DATA

The first phase of this task is to develop the system architecture and a logical database design for the relational database. The architecture and logical design will provide the foundation for integration and distribution of data in many of ITD's business data systems. While there are many factors that contribute to the success of an LRS system, the data model design is a fundamental one because it lays the foundation for the LRS and LRS-enabled data sharing.

A centralized data repository/warehouse should be established for geospatial databases that are maintained by or used extensively by ITD (assuming such a repository does not already exist). At a minimum, the repository should include the following geospatial data:

- The official state roadway network database that will serve as the foundation for the GIS-based LRS;
- Geospatial boundary files for political and administrative boundaries that are represented in the current MACS system (e.g., counties, urban areas, tribal boundaries); and
- Other statewide geospatial databases, not maintained by ITD, that are used for creating cartographic products and displays (e.g., hydrography, public lands, Census boundaries, Census TIGER street network, etc.)

The geospatial data repository should include metadata documentation for each database that provides, at a minimum, basic information in the source, geographic extent, and projection; and a data dictionary. Databases in the repository should be available to all ITD staff.

ITD GIS staff should be responsible for overseeing the geospatial data repository; and for maintaining and updating the official state roadway network database, including the assignment of segment code identifiers to each roadway segment.

The geospatial data repository should eventually become an integral component of the enterprise data warehouse being developed by the ETS Division.

5.3 Develop/Acquire Procedures for Implementing a Route/Milepost LRM

ITD should begin its development of a new LRS by building or purchasing a procedure that will enable it to locate and display linear and point features based on a location defined by ITD segment code, milepost, and offset. The procedure should enable users to enter a segment code, milepost, and offset(s); and have the corresponding point position or linear event displayed on a GIS map. Alternatively, a user should be able to query a position on a map; and obtain the segment code, milepost, and offset values for that position.

Initial development and testing of this procedure should be carried out using data from the current MACS linear datum. Successful development of this LRM procedure will enable the MACS to be migrated from its current mainframe environment to a client-server-based GIS (see Recommendation 5.4 below); and provide an interactive or automatic method of creating the Milepost log book.

5.4 Migrate MACS from Mainframe to Server-Based RDBMS

The MACS segment code and milepost LRS need to be migrated from its current mainframe environment to a relational database management system operating in a client-server environment. The migration should take place so as not to disrupt current MACS operations. This suggests that a copy of the MACS linear datum database should be exported from the mainframe and imported into an RDBMS (presumably Oracle or SQL Server). All QA/QC and functionality testing should be conducted off-line on the RDBMS copy, while the mainframe version remains operational as the agencywide production LRS. Any updates to the MACS that take place subsequent to the initial copy should be logged or preferably deferred until testing is completed, and the GIS staff are confident that full functionality is available in the RDBMS version. At that point, the server version of MACS should be updated with any changes, put on-line as the production version of MACS, and the mainframe version retired from service.

As part of the migration process, the MACS segment code and milepost linear datum should be separated from the peripheral attribute, data such as political and administrative boundaries, functional class, scenic byways, etc. These data items should be converted either to geospatial boundaries (e.g., political boundaries); or linear events (e.g., functional class) linked to the MACS datum. The assumption is that the polygon layer for these boundary files already exist or can be created easily. Or else ITD may need to continue carrying the boundary information in tabular format until boundary layers can be created. Part of the off-line testing will ensure that the information contained in these peripheral attribute files can be accurately linked back to the segment code and milepost in MACS.

The migrated MACS will become the first LRM in the new ITD LRS.

5.5 Demonstrate the Use of the Route/Milepost LRM for Integrating and Displaying Agency Databases in a GIS Environment

The GIS staff should work with one or more ITD Divisions or Districts to identify and develop an application to demonstrate how the Route/Milepost LRM procedure can be used to:

- Locate, display, query, select, and edit agency data in a GIS;
- Use GIS spatial analysis tools to integrate and analyze data from two different agency databases; and
- Facilitate routine reporting or analysis tasks.

The primary objective is to help market the LRS to initially skeptical organizational units and staff, and to identify additional requirements for new functions, LRMs, and data from potential users.

5.6 Develop/Acquire Procedures for Implementing Additional LRM Procedures

Additional LRM procedures can be added to support the integration of other agency databases. Three potential candidates for inclusion in the LRS are the following:

1. **Route/Coordinates –** After Route/Milepost, this LRM appears to support the largest number of potential databases. Locational information for many point features (e.g., sign inventories, crashes, milepost locations, etc.) is currently or could be collected using GPS technology, which provides geographic coordinates rather than a linear measure along a route. Development of an LRM would use the coordinate information and a sign route to "snap" the feature to the appropriate road segment centerline, or to find the closest centerline location and provide an offset distance perpendicular to the centerline.

2. **Route/Milepoint –** Videologs and photologs are typically referenced using a route and cumulative milepoint distance measurement, rather than resetting the distance measuring equipment at each milepost reference marker. Route/milepoint is also the most common LRM, and should be relatively straightforward to incorporate into an LRS.

3. **Project Stationing –** Several of the Districts indicated a desire to locate planned or completed projects on a map, showing the extent of the project as a linear feature. Project plans are referenced using survey stationing procedures, where measurements are made with respect to a known geodetic reference point (e.g., a U.S. Geological Survey (USGS) geodetic marker). Development of a stationing-based LRM would require a database of geodetic monuments or base station markers, and a procedure to convert from stationing measures to direct linear units (e.g., feet or meters).

With the incorporation of each new LRM, new applications should be developed to showcase the enhanced capabilities and additional agency databases that are now accessible through the LRS.

In addition, as new LRMs are added to the LRS, ITD should initiate a project to locate each milepost sign using GPS coordinates. This will establish an accurate baseline for matching route/milepost linear references to the other LRMs. It will also establish an historical baseline for positioning milepost signs that get removed or destroyed.

Figure 5.2 is a high-level Concept of Operation for an LRS-based geodatabase. It shows how information will be shared between the new system and other existing ITD systems. Figure 5.3 shows how data can be managed and served up to different types of users with different applications (desktop and web based).

Figure 5.2 LRS Geodatabase Concept of Operation

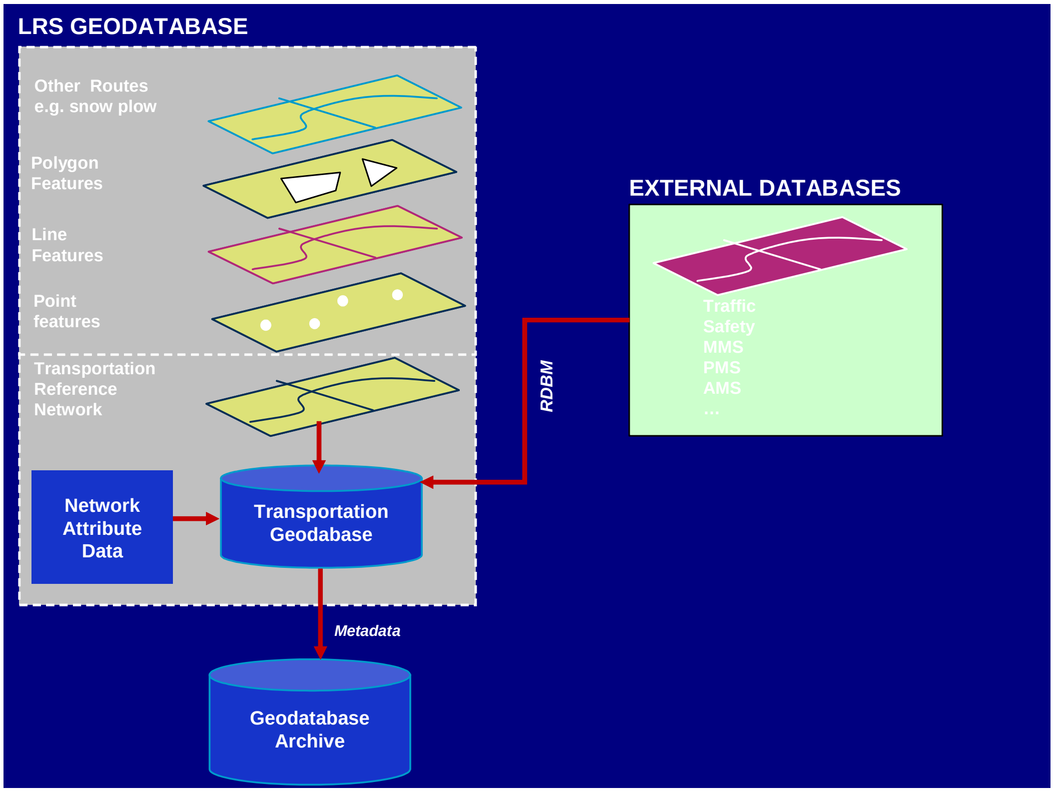
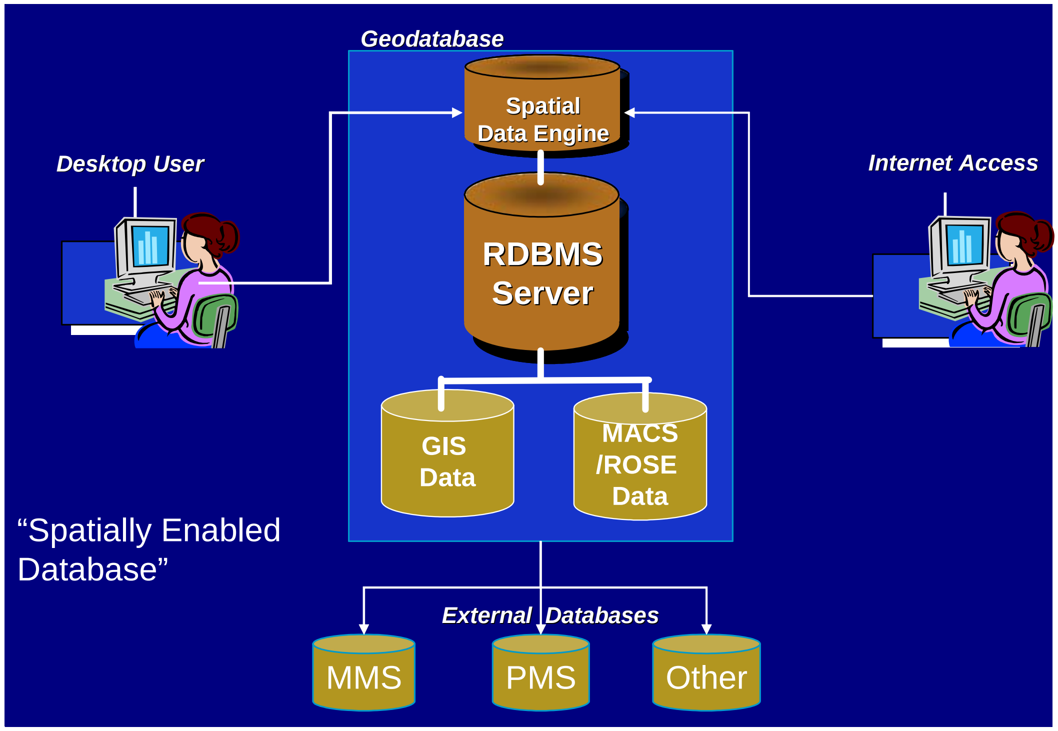


Figure 5.3 LRS System Overview



6.0 Cost Estimate

This section presents an estimate of the cost to build a GIS-enabled LRS. The costs to migrate from the current mainframe-based MACS LRS to a GIS-based LRS operating in a client-server environment will potentially include several procurement actions and considerable staff time for ITD at the headquarters and in various district offices. These cost estimates do not include any costs associated with clean-up or enhancing the locational accuracy of any programmatic or business database that is managed by an organizational unit other than the GIS/LRS division (e.g., crash records, road inventory, signs, etc.) For the purposes of this study, it is assumed that responsibility for the locational accuracy and integrity of these business databases remains with the organizational unit that currently maintains them.

The following subsections identify the major cost components associated with the migration, and provide a ballpark estimate of the lower and upper limits of potential costs for each component.

6.1 Overall Project Management, Outreach, and Internal Marketing Activities

Obtaining overall buy-in from the different organizational units in ITD will require considerable level of effort from the GIS project manager to prepare and make presentations for senior management, meet with internal stakeholders groups, coordinate various development activities, etc. Based on the experience of other state DOTs, we estimated that this level of effort may require 50 percent of the project manager's time over a two-year, phase-in period. Typical budget for this task can be in the range of $150,000 to $250,000.

6.2 Data Clean-Up

Several of the case study sites clearly identified that clean-up and enhancement of key LRS databases was critical to the overall success of their LRS project. At a minimum, database clean-up includes the geospatial road network and the current MACS LRS linear datum. Additional geospatial data enhancement may include creation or clean-up of geospatial boundary databases and linear events for features that are migrated out of the MACS (e.g., counties, urban areas, functional classification, etc.). The costs for data clean-up could be done using in-house GIS staff or through contract labor. The costs for this activity could vary from $250,000 to $500,000, depending on the quality of the existing databases. Staff from district offices and various headquarter offices, especially data custodians, should be encouraged to participate in the data clean-up activities.

6.3 Software Purchase

New or additional software licenses may need to be purchased for GIS, relational database management, and web servers. The overall cost of this can vary considerably, depending on whether existing software licenses (e.g., ESRI, Oracle, and SQL) are sufficient, and whether ITD decides to purchase software from other developers (e.g., Intergraph, Bentley, EXOR). Even if ITD builds its LRS using current software platforms, it may be necessary to purchase additional licenses (e.g., more ArcGIS seats) or new modules (e.g., Network Analyst or ArcSDE server) to fully implement the new LRS system. Software procurement costs could range from $50,000 to $500,000, depending on the platforms that are selected and the licensing model.

6.4 Hardware Purchase

It may also be necessary to purchase new or upgrade existing server hardware to meet the performance requirements needed for an agencywide web-based GIS server. Costs for hardware upgrades could range from $25,000 to $100,000, depending on the existing systems and anticipated system usage.

6.5 Database Design and Development

In this task, data needs will be translated to a physical data model that will serve as the schema for the LRS database. There is typically a four-step process in developing the data model:

- **Step 1. Develop a logical database design.** An object model diagram will be developed to show all the entities and relationships in the database, and identify any potential gaps that may exist in the data model.
- **Step 2. Define the feature representations for each object need.** The types of feature representations that are typically used are point, line, area, or raster data. In addition, linear referencing methods also are defined, including route-systems and events.
- **Step 3. Define the geometry of each object together with relationships that exist between the features, as well as validation rules, including attribute validation, network connectivity, relationships, and custom rules.** These validation rules will ensure database integrity by validating all data items entering into the database.
- **Step 4. Organize the geodatabase structure.** The organization is typically defined by systems of features, thematic groups, departments of responsibility, and any topological associations that exist between the features. This includes defining the final relationships and rules that will be present in the geodatabase.

After building the database schema, the appropriate data sources for each proposed feature class in the geodatabase will be identified and evaluated. New facility types or business attribute data may need to be developed if they are required entities in the geodatabase, but are not presently available in any existing databases at ITD. Even in cases where data do exist, conversion from existing formats and migration from existing data systems might still be necessary. A data migration plan is needed in order to determine the priorities and timeline for developing new GIS data, populating missing attributes desired by various area stakeholders, and converting and migrating existing data. A Metadata plan is also needed in order to maintain metadata automatically. A temporal data management plan will describe the best strategy to manage the temporal aspect in the database system, and allow base and future data to be represented in the database. Cost for this task could be in the range of $200,000 to $500,000, depending on the complexity of the database relationship.

6.6 Software Enhancements and Application Development

Regardless of the commercial software platform(s) that are purchased for the LRS, additional software enhancements and certain custom applications will have to be developed to address unique characteristics of ITD data, and to address stakeholder requirements for user interfaces and special reports and outputs. An LRS needs to have at least two types of applications: 1) applications to manage the database and 2) applications to empower end-users. The primary function of the maintenance applications is to help the ITD staff to manage transportation network features and their associated business data. It also enables the editing of other information that is less directly associated with transportation features, such as jurisdiction boundaries. The LRS management staff should be able to use this type tool to do rerouting or updating of the centerline while maintaining necessary data relationships in the LRS.

A key factor in obtaining broad-based agency buy-in for the LRS project is to demonstrate to potential users how the LRS and its ability to integrate agency data can address current analysis and reporting tasks for specific stakeholders. Consequently as new databases and capabilities are incorporated, the GIS staff should take a proactive role in working with other ITD business units to identify potential applications, and then assist in developing tools and procedures to effectively utilize LRS in those applications. End-user application can be developed to export data to the formats required by systems related to the LRS system. From the results of the user requirements analysis, there should be known requirements regarding how to provide data to different users in a variety of manners, and in what format the data should be for each user. Data reporting application can be developed to enable users to build customized queries on the geodatabase, and extract data by selective extraction or clipping by preset areas.

Users can then export the selected data items to their desired formats so they are readily applicable for their own business uses.

ITD should budget for $200,000 to $350,000 for immediate software enhancements, and additional $50,000 to $100,000 per year for at least five years thereafter for future updates, enhancements, and new application capabilities.

6.7 Training

Another measure of success of the integration of GIS into ITD business practices is growth of GIS literacy and use among non-GIS ITD staff. This will require both initial and ongoing GIS training and support, which will also help to maximize the use of the LRS system. Training can be done using in-house staff, contract support, or a combination (e.g., support initial GIS training through ESRI-certified training courses, and use GIS staff to provide ongoing technical assistance or targeted training for specific applications). Training will be an ongoing cost, but the annual budget can be adjusted, depending on the desired speed of adoption throughout the agency. A reasonable minimum annual training budget might be $20,000 to $30,000, including GIS staff time. The plan should set aside training budget for at least five years ($100,000 to $150,000 total).

6.8 System Maintenance

System maintenance is a major issue that any organization needs to address. A system maintenance plan needs to be developed with well thought-out procedures for the maintenance of all spatial and nonspatial data stored in the LRS system. The maintenance plan will help ITD define data management responsibilities in order to keep the GIS accurate and up to date, and the procedures used to update the LRS database or the GIS applications. The maintenance plan also will specify how often each data element should be updated; and how metadata should be updated accordingly so that end-users can readily ascertain the source, accuracy, currency, and types of data available to them. It is common that system maintenance fee would account for 10 to 25 percent of total project cost.

Table 6.1 provides the ballpark cost estimates for developing a GIS-enabled LRS system. The lower range estimate is $1.45 million, and the upper range is $3.55 million. Since no detailed function requirement analysis has been conducted for an LRS system, the estimates are mostly based on our experience and research results for building similar systems.

Table 6.1 Ballpark Cost Estimates

Tasks		Low ($1,000k)	High ($1,000k)
1.	Project Management & Stakeholder Buy-In	150	250
2.	Data Cleanup	250	500
3.	Software Purchase	50	500
4.	Hardware Purchase	50	100
5.	Database Design and Development	200	500
6.1	Software Enhancement (Initial)	200	350
6.2	Application Development (5-year)	250	500
7.	Training	100	150
8.	System Maintenance	200	700
Total		1,450	3,550

7.0 Benefit Analysis

In order to justify the heavy investment of building an LRS system, it is important to conduct an analysis for benefits, cost savings, and Return On Investment (ROI) achieved through the use of LRS system. Detailed ROI analysis is not feasible in this study, because cost saving needs to be built upon a thorough understanding of the existing cost of LRS-related activities within ITD. MACS is centrally managed; therefore, it is easy to estimate the cost associated with MACS. However, different district offices and business areas are creating, editing, and managing locational data in various ways; and it is not possible to get a good estimate of cost saving without very detailed business analysis. Our recommendation is for ITD to perform a detailed ROI analysis before signing off the vast investment for any proposed LRS system.

But ITD can benefit from the work conducted by other state DOTs in support of their decision-making for LRS development. The ODOT provides an excellent example as it is in the process of building an LRS that will be designed to replace their current highway inventory. The new LRS called TransInfo will include state roads first and locals second; and will eventually track history of the network. The estimated total cost for building the TransInfo is $5.2 million, including in-house staff resources, as well as a contract value of $3.2 million with Exor in partnership with Cambridge Systematics and TC Technology. ODOT conducted a detailed Cost and Benefit Analysis for implementing the proposed TransInfo system, including the actual cost of software and services as contracted, as well as a refinement of other project costs and benefits. In addition, the ODOT analysis includes the assumptions upon which the estimates rest, the potential risks related to completing the project within the projected cost, and actually attaining the estimated benefits. The Return of Investment (ROI) analysis is based on the identified assumptions, information gained from similar agencies that have already implemented Asset Management solutions, and estimated savings from cost avoidance and efficiency gains. Table 7.1 illustrates that ODOT will likely see a return on investment within five years after implementation. The ROI analysis concludes that the TransInfo project is both cost-effective and in line with ODOT's goals. Therefore the Project Team for ODOT recommends that the project move forward. Please see Appendix D for detailed information about the ODOT ROI analysis.

Table 7.1 ODOT ROI Analysis

ROI Analysis			
Project Costs	***Total Build (Costs through 2010)***	***5 Yrs of Ownership***	***Total Build + 5 Yrs of Ownership***
Costs			
Internal Staff	$1,761,260	$219,750	$1,981,010
Hardware Maintenance (SDC)	$31,200	$156,000	$187,200
Licensing	$322,800		$322,800
Software Maintenance		$527,693	$527,693
Exor	$971,323	$303,014	$1,274,337
Contract Support (DOJ, PM, Data, Interface)	$843,417		$843,417
External Quality Assurance	$70,000		$70,000
Total Costs	$4,000,000	$1,206,457	$5,206,457
Tangible Benefits			
Increased Productivity (data management/report and query writing)		$1,363,028	
Reduced Training Time		$342,239	
Eliminate ITIS and Features Inventory Support and Maintenance		$679,491	
Eliminate Contracted Improvements on ITIS		$250,000	
Improve Pavement Program Efficiency		$540,000	
Benefit of establishing enterprise platform for corporate assets		$800,000	
Benefit to Public of Improved Safety Data		$2,100,000	
Total Benefits		$6,074,757	$6,074,757
Project Payback - After Implementation			Less than 5 years

Source: ODOT TransInfo: P290s Costs and Benefit Report V2, Draft, 2009.

Appendix A. Interview List

1. MACS System Manager;
2. District 5;
3. District 4;
4. District 3;
5. District 1;
6. District 6;
7. District 2;
8. Aeronautics Division;
9. Enterprise Technology Services(ETS);
10. Planning Services;
11. Public Transportation;
12. Intermodal and Roadway Planning Groups;
13. Highway Operations; and
14. Highway Project Development.

Appendix B. Interview Guide

ITD LRS Stakeholder Workshop

Interview Guide

1. **Interview Objectives.**
   a. Review and validate the recommendations in the LRS Needs and Recommendation Report by GeoDecision, 2006.
   b. For stakeholders to articulate additional information needs and data flow business issues with respect to LRS.
   c. For the consultant team to understand business issues and user needs for an developing an LRS at ITD
2. **Interview Approach.**
   a. Each stakeholder interview will last 60 to 90 minutes. The overall procedure of the interviews:
      i. Review your current business process related to the utilization of LRS in its current format, and discuss issues or problems with the current system/process.
      ii. Discuss your perceived needs for an LRS, and discuss potential issues or problems related to your business area.
3. **Discussion Guide.**
   a. Business Process Overview (10 to 15 minutes):
      i. High-level description of your business area, how you conduct your work, and how you utilize LRS in its current form.
      ii. Identify key issues related to LRS.
   b. Issues/Problem Identification (10 to 15 minutes):
      i. Discuss your information needs and data compatibility issues with LRS.
      ii. Identify specific problems with using the current LRS. Please provide examples.
      iii. How do you presently overcome the problems as described?
   c. Needs Assessment (30 to 45 minutes):
      i. Discuss what GIS data that you currently have should be included in the LRS system. Identify data sources, evaluate data accuracy and

currency. Identify other business units that may be interested in accessing these data items.

ii. Discuss what GIS data that you currently do not have, but would like to have them included in the LRS system. If possible, identify the business units that own or manage these data items.

iii. Identify any changes in business processes that you intend to implement that may impact the development of the LRS at ITD. This should also be any new data requirements or new systems to be developed.

iv. Validate the need list documented in the 2006 Needs study, and identify additional needs/issues related to the development of an LRS. Discuss the needs that are most relevant to your business needs.

v. Identify changes to the LRS that would help you perform your business functions better.

vi. Discuss how you would like to access, analyze, and display data in the LRS system. How important is historic data to your business needs?

d. Wrap-up: Summary and Follow-Up Action Items (10 to 15 minutes):

i. Summarize discussion and identify follow-up action items and priorities.

ii. Identify any documents or other sources of information that should be analyzed in the project. If available, please bring these to the interview.

iii. Identify key contact person(s) and provide a list of existing transportation GIS information

Appendix C. Vendor Response and LRS Product Information

1. ESRI

ESRI's Transportation Solution supports linear referencing in three ways:

1. Generically using COTS event editing and geoprocessing tools that provide the user with the flexibility to determine how linear referencing will be managed;
2. Using predefined workflows that can be configured for the client's specific business requirements; and
3. Through custom development that leverages COTS products and workflows to meet specific or uncommon requirements.

Generic

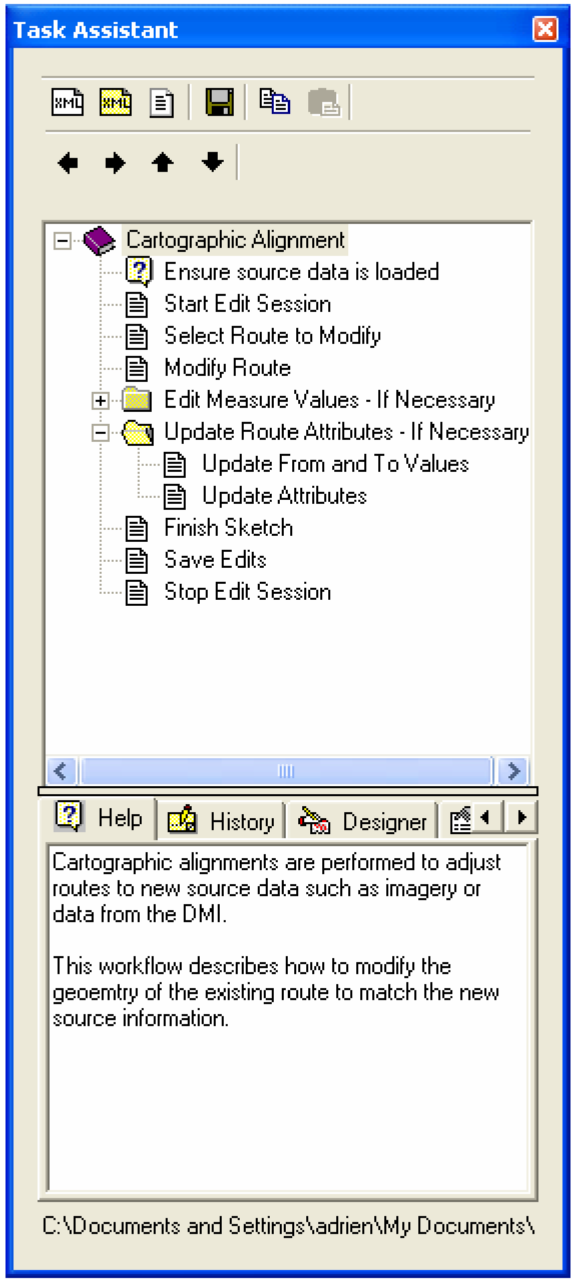
ESRI has developed linear referencing tools for the Transportation Solution that can work as an addition to ArcGIS Desktop solutions. In addition to the COTS LRS tools available in the core desktop product, ESRI has created an event editing toolbar that can be used to easily manage tabular line and point events as if they were features.

- Create Events by graphically placing a location along a route.
- Delete Events by graphically selecting the event to be deleted.
- Move Point Events using the cursor to drag the event along the route.
- Split Line Events by selecting a location on the map.
- Modify Line Events by selecting the end of an event and dragging it along the route.
- Modify Shared Line Events by selecting the intersection of two line events, and editing them simultaneously to ensure coincidence.

These tools indicate the measures on the screen in the map display to facilitate accurate placement of event data based on measures along the route. They can be used as a standalone toolbar in ArcMap, or in conjunction with the workflows included in the Transportation Solution.

Predefined Workflows

The Transportation Solution includes a Task Assistant to help manage the editing and maintenance of linear referencing data. Using the predefined workflows within the Task Assistant, editors are guided through the step-by-step processes required to maintain highway data using linear referencing.



This approach eliminates the need to learn a complex series of steps, sorting through myriad toolbars, or even knowing which button to click. All that is required is that the user has a general understanding of editing in ArcMap and a strong understanding of the DOT's highway maintenance business rules. The workflows can be easily configured to implement the DOT's specific business rules. Some of the predefined workflows included with the Transportation Solution are:

- **Annexation –** Change in jurisdiction of a highway;
- **Cartographic Alignment –** Update to cartographic accuracy of a roadway;
- **Centerline Management –** Sharing highway data between highway management, traffic safety, and Emergency Services;
- **Create Events from Features –** Conflating highway data from external systems and GPS coordinates;
- **Manage LRMs –** Transferring event data from one LRM to another;
- **Manage Overlapping Routes –** Manage route data and event layers where multiple routes share a roadway; and
- **Realign Routes –** Managing the location of event data during highway realignment, including the preservation of history for closed and retired roads.

This approach is appropriate for most state departments of transportation and local highway management agencies where most data editors have a strong understanding of an agency's business rules, but require managed workflows to facilitate maintenance and data integrity.

The Transportation Solution is built from ESRI's native technology, therefore, is compatible with all ESRI products.

Custom Development

The Transportation Solution can be fully customized to support an agency's specific needs. Existing workflows can be configured to support custom geoprocessing tools created through Model Builder, Python, or ArcObjects in ESRI's developer environment. While it is envisioned that most DOTs will not require a custom solution, ESRI recognizes that some DOTs may have special needs that are unique to a given agency. Custom applications created to support these specific requirements can leverage the components of the Transportation Solution to create a truly world class LRS implementation that is tailored to an agency's specifications.

ESRI's Transportation Solution can handle any number of LRMs regardless of type. This is facilitated by the ESRI Transportation Data Model. In this model, measures are stored separately from the geometry in the form of calibration points. An LRM Position table stores an LRM location reference for each calibration point. A calibration point can be associated to a location reference for any or all LRMs used by an agency. Since the base geometry does not house the measures, any number of LRMs can be applied to the same geometry through calibration. This approach also supports the assignment of LRM measures to multiple geometries in order to support various representations of the highway data at a variety of scales. A simple set of functions are included in the Transportation Solution to aid the user in creating new LRMs and transforming events quickly and easily from one LRM to another. The data model supports the storage of multiple LRM references within the event tables or as a related table so events can be easily displayed on a variety of LRMs without the need for repeated transformations.

The cost of the Transportation Solution for handling LRS is $5,000 per seat. It is run from ArcGIS Desktop, although it can be configured to run in a Server application. Training is provided by ESRI's training staff, and can be offered on-site, at the Regional Office, or at the ESRI Headquarters in Redlands, California. Regular training costs apply.

2. Exor

Exor referred to its company product web site for more information about its LRS software. Below is an overview of the Exor Highways™ product from its corporate web site:

> *Exor Highways™ is the industry's most flexible and sophisticated system for highways owners, operators, managers, and stakeholders. Regardless of the size of your organization or the way you work our distinctive solution flexes to reflect your business practices both now and into the future. Flexibility is key to our philosophy and that's why we don't force you to follow a prescriptive model.*
>
> *Our product set delivers an unrivalled breadth of functionality for effective management and planning of the road infrastructure. Its modular architecture means you can implement individual applications or a comprehensive 'cradle to grave' asset management system. The choice is yours.*
>
> *The Enterprise Edition further extends user choice by enabling non-Exor applications to participate in your overall highways management vision and strategy. Our Asset Hub™ integrates your entire asset data regardless of how or where it is stored so you can retain existing applications yet benefit from a single corporate view of your network and associated assets.*
>
> *As the need to share information with stakeholders becomes increasingly important we recognize it is not just your users that require access. Our advanced technology also enables you to permit secure access from trusted external applications via industry standard protocols. All of course without compromising the integrity of your corporate information.*
>
> *With congestion management becoming a political imperative for many of the world's road operators reliable real-time sharing of data between local government, contractors, utilities and other stakeholders is becoming essential. In the UK, for example, the Traffic Management Act places a legal obligation on road owners to understand and manage all activities and events that affect traffic*

> *flow. And if the local Network Manager fails to plan effectively they face the sanction of legal intervention by the central authority. At a time when data integration is becoming a reality, lack of complete and current information is no longer an excuse. Exor Highways offers you choices for success.*

Exor stated that its product is able to support Multiple LRMs as needed by ITD. It also confirmed that Highways will work with ESRI products. For license pricing information, Exor referred to ODOT because they just completed the contract negotiation with ODOT with detailed license and pricing information for TransInfo (see table below).

TransInfo System Costs

Project Costs	Total Build Costs	Year 1	Year 2	Year 3	Year 4	Year 5	Total Build + 6 yrs Ownership Costs
COTS Software Support							
System Architecture	$251,074	$ -	$ -	$ -	$ -	$ -	$251,074
Design/Construction	$422,256	$ -	$ -	$ -	$ -	$ -	$422,256
Implementation	$102,557	$ -	$ -	$ -	$ -	$ -	$102,557
Management & Tracking	$156,928	$ -	$ -	$ -	$ -	$ -	$156,928
Project Closure	$38,508	$28,014	$ -	$ -	$ -	$ -	$66,522
Enhanced Support	$ -	$55,000	$55,000	$55,000	$55,000	$55,000	$275,000
Staff & Contracted Personnel							
Information Systems Staff	$934,430	$18,000	$18,000	$18,000	$18,000	$18,000	$1,024,430
Business Staff	$790,330	$25,950	$25,950	$25,950	$25,950	$25,950	$920,080
DOJ / Data / Interface / Oracle / Project Mgmt.	$796,167	$ -	$ -	$ -	$ -	$ -	$796,167
Hardware Maintenance							
Operations Support (SDC)	$31,200	$31,200	$31,200	$31,200	$31,200	$31,200	$187,200
COTS Software Maintenance & Licensing							
TransInfo Software Licensing	$322,800	$ -	$ -	$ -	$ -	$ -	$322,800
TransInfo Software Maintenance	$ -	$102,219	$102,219	$102,219	$106,102	$114,934	$527,693
External Quality Assurance							
QA Assessments	$153,750	$ -	$ -	$ -	$ -	$ -	$153,750
Total System Costs	**$4,000,000**	**$260,383**	**$232,369**	**$232,369**	**$236,252**	**$245,084**	**$5,206,457**

Source: ODOT TransInfo: P290s Costs and Benefit Report V2, Draft, 2009

3. Intergraph

Intergraph offers Multilevel Linear Referencing System capabilities through its GeoMedia and GeoMedia Transportation Manager Software. The software offers the ability to manage both single level and multilevel linear referencing system (MLRS) out of the box. The software provides a clean GUI interface for building and maintaining the LRS/MLRS data model and data. Intergraph also offers optional add-on components, such as GeoMedia Fusion for data conflation capabilities, and GeoMedia Transaction Manager for long-term transaction management.

The GeoMedia Transportation Software provides LRS data management and analysis. Also included in the product is the ability to manage route tables necessary for routing applications using the same LRS network data. See the "working with"/help documents for more technical capabilities of the products.

Intergraph's GeoMedia Software stores and manages data using Oracle's Geometry data column in Oracle's format. There is no proprietary software needed to access the data generated by GeoMedia Products. Intergraph's software can also connect to ESRI data sources through web services, Safe Software's FME, or access shapefiles directly.

Software Cost Information:

- Geomedia Professional $9,434
- Geomedia Transportation Manager $7,632
- Geomedia Transaction Manager $5,088
- Geomedia Fusion $9,540

Note: Prices listed are per seat. An additional discount will be provided based on the number of licenses required for the solution.

Optional implementation services costs will vary depending on how the DOT elects to implement the solution. Multilevel linear referencing systems can be complex and Intergraph would need a better understanding of the business requirement to provide a more accurate pricing plan. Careful consideration should be given to the agencies business data management plan and data management workflows when considering MLRS.

A typical project might include a brief needs assessment to evaluate the DOT business rules, data sources, and workflows, data modeling, data migration, data validation, implementation or roll out plan, custom workflow development and training plan, and minor custom coding if a function is needed that is not provided out of the box.

The following is a response to the questions concerning Linear Referencing Solutions posed on behalf of Idaho Department of Transportation.:

(1) Which Bentley software packages support LRS management; What is the main strength and weakness of your products when compared with competitor's products;

Location Data Manager Express (LDMx)

Bentley Location Data Manager Express (LDMx)® is a cost-effective software solution that enables transportation organizations to store, reference, manage and analyze location data stored in an Oracle database. LDMx handles the unique requirements of users working with data developed by a variety of linear referencing systems (LRS). LDMx is the core engine driving the Iowa LRS solution that is the most advanced implementation of our LRS technology today and the sole solution that Bentley endorses at this time.

The Iowa LRS has four major components:

1. The LDMx engine that together with the Oracle database provides the system network, network verification tools, linear reference system transformations and dynamic segmentation tools. Bentley LDMx offers a fully integrated set of functions and procedures for managing, analyzing and reporting on spatial data. This component is independent of any GIS system. It is strictly the engine and does not include an interface for editing/maintaining the data.
2. The Oracle database with Oracle Spatial – a database with the necessary structures to create, manipulate and query spatial data. Other databases are currently unable to handle the multiple geometries and custom data types required. Oracle 10g and 11g both 32-bit and 64-bit are supported
3. The Iowa LRS – A multi-level linear referencing system implemented using the NCHRP 20-27 specifications. It includes support for multiple cartographic representations, multiple network representations and multiple route naming. Business data integration is supported using transformations between linear referencing methods, networks and cartographic representations by associating all linear data with a central linear datum. This module interfaces with the LDMx functions for performing the transformations.
4. The Iowa LRS Maintenance Tool – This module provides a graphical user interface (GUI) for editing and maintaining the model data. This module is a customized interface using Intergraphs's GeoMedia GIS engine and GTM (GeoMedia transaction manager) and Oracle Workspace Manager.

It is important to note that while the Iowa LRS system uses the Intergraph tools for the GUI interface, end users can access and query the data using any GIS system they choose, including ESRI products.

The information contained in this document is proprietary of Bentley Systems, Incorporated.
This information is not to be disclosed to any third party without Bentley's express prior written consent.

Strengths of the Iowa LRS Solution

- Readily available solution that has already been developed
- The Iowa LRS Maintenance Module is available at no charge from Iowa DOT. The software modules must be purchased from the respective vendors and some implementation services are required.
- It is a multi-level LRS that can handle many LRS methodologies including those mentioned: Route/Milepost, Route/Coordinates, Route/Milepoint, Stationing and address range
- Highly scalable to multiple users and processors
- Can combine spatial and aspatial data for use among any transportation department
- A dynamic segmentation engine processes event tables. A programmable set of functions and procedures enables you to control the flow of the dynamic segmentation process.
- An overlay engine provides the capability to compare and correlate multiple linear data sets.
- Can be adapted to work with existing database schemas with some modification.
- Support for temporality and long transactions through implementation services

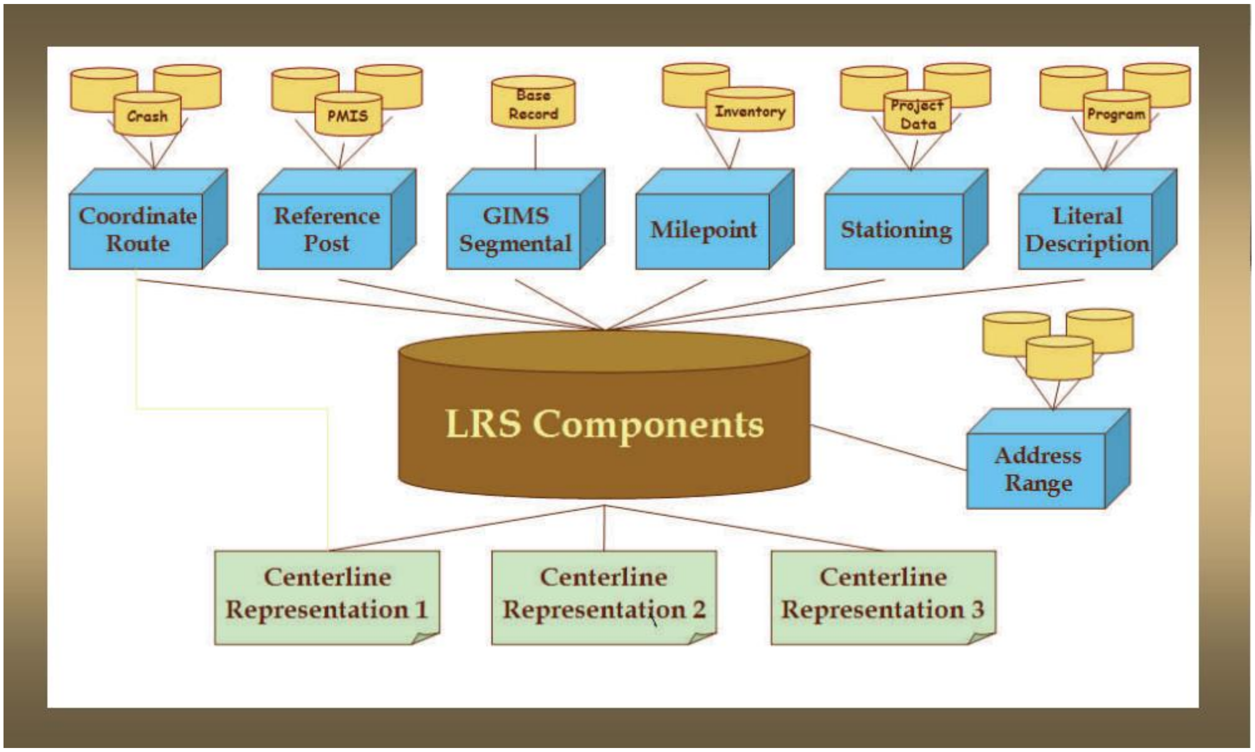
Weaknesses

- Operates with a single database vendor – while some may consider this a disadvantage, we feel it is the only database solution that provides the necessary structure to support a true NCHRP 20-27 compliance
- Requires the Intergraph GeoMedia modules – while some may consider this a disadvantage, they provide the strongest tool set for providing the necessary interface to the Oracle data types required. Together with the Bentley LDMx engine, they form a proven and readily available solution available to all DOTs without having to pay for the integration services already completed at Iowa DOT.

(2) Review how your software packages could potentially meet the ITD needs for multi-level LRM, including Route/Milepost, Route/Coordinates, Route/Milepoint, Stationing and address range

Data integration is supported through transformations among methods, networks, and cartographic representations by associating with a central object referred to as a "linear datum. Bentley LDMx offers a fully integrated set of functions and procedures for managing, analyzing and reporting on spatial data. The software supports three standard linear referencing methods—route measure, route duration and segment offset—as well as a coordinate route method.
You have the flexibility to locate events using a variety of methods and convert from one form of reference to another. For example, you can create a geometric point from a linear reference, or convert a global positioning system (GPS) point to a linear reference. This ability to convert between referencing systems lets you quickly analyze and compare field data.
For the Iowa LRS, the following diagram provides an overview:

The information contained in this document is proprietary of Bentley Systems, Incorporated.
This information is not to be disclosed to any third party without Bentley's express prior written consent.



(3) ITD mainly uses ESRI software to support their general GIS needs. How can your software package be compatible with ESRI products;

While the Iowa LRS Maintenance Tool relies on the GeoMedia products, the end user is free to access/retrieve data using the ESRI products.

(4) Provide information regarding the costs for system acquisition, deployment, licensing and maintenance fees, and training;

<u>Bentley Products:</u>
Bentley LDMx – 1st Processor:
List Price Purchase: $15,000 each
Annual Maintenance: $3,000 each
Bentley LDMx – 2nd and subsequent Processors:
List Price Purchase: $10,000 each
Annual Maintenance: $2,000 each

<u>Other Products:</u>
Oracle Spatial Database: check with vendor
Oracle Workspace Manager: check with vendor
Intergraph GeoMedia: check with vendor
Intergraph GTM Transaction manager: Check with vendor

<u>Iowa DOT LRS Maintenance Tool</u> – No cost to other DOTs

The information contained in this document is proprietary of Bentley Systems, Incorporated.
This information is not to be disclosed to any third party without Bentley's express prior written consent.

Professional Services for Implementation and Configuration:
It is impossible to put an estimate on this without knowing more about the ITD data. Our Professional Services team can assist in assessing and verifying the condition of the network data but would not actually be involved in fixing problems with the data. Costs also depend on the existing/proposed database schema.

(5) Provide examples of State DOTs that have implemented Bentley LRS software.

The following are using the LDMx engine (without the Iowa LRS modules):

TXDOT – in their CRIS project (crash management system)
OKDOT – in their GRIP System
MSDOT - as part of their SAM safety system
NVDOT – in their internal systems and processes
TNDOT – in their internal systems and processes

The information contained in this document is proprietary of Bentley Systems, Incorporated.
This information is not to be disclosed to any third party without Bentley's express prior written consent.

Appendix D. ODOT ROI Analysis Results

Oregon Department of Transportation

Asset Management Integration Program

TransInfo

P290s Costs and Benefits

Version 02 - Draft

Author: Lorena Lambert and Marty Adolf

Last Save Date: September 2, 2009

History

Version	Description	Signature	Date
0.01	Initial draft for Leadership Team Review	Lorena Lambert	02/08/08
0.01	Approved	Lorena Lambert	04/15/08
v02 b07	Draft of revision	Marty Adolf	07/01/09

Table of Contents

1. Purpose

The purpose of this document is to provide revised cost and benefit assumptions to support the implementation of the TransInfo system. This document is a revision to the initial Cost and Benefit document that was approved prior to the preliminary analysis. As a result of the preliminary analysis, more costs and benefits have been identified and are detailed here.

2. Executive Summary

This Cost and Benefit Analysis is a revision of the initial assessment of the costs and benefits of implementing the proposed TransInfo system. It is being submitted at the conclusion of the preliminary analysis phase and includes the actual cost of software and services as contracted, as well as a refinement of other project costs and benefits. In addition, this analysis includes the assumptions upon which the estimates rest, and the potential risks related to completing the project within the projected cost and actually attaining the estimated benefits. The analysis is based on the identified assumptions, information gained from similar agencies who have already implemented Asset Management solutions, and estimated savings from cost avoidance and efficiency gains.

ROI Analysis			
Project Costs	***Total Build (Costs through 2010)***	***5 Yrs of Ownership***	***Total Build + 5 Yrs of Ownership***
Costs			
Internal Staff	$1,761,260	$219,750	$1,981,010
Hardware Maintenance (SDC)	$31,200	$156,000	$187,200
Licensing	$322,800		$322,800
Software Maintenance		$527,693	$527,693
Exor	$971,323	$303,014	$1,274,337
Contract Support (DOJ, PM, Data, Interface)	$843,417		$843,417
External Quality Assurance	$70,000		$70,000
Total Costs	$4,000,000	$1,206,457	$5,206,457
Tangible Benefits			
Increased Productivity (data management/report and query writing)		$1,363,028	
Reduced Training Time		$342,239	
Eliminate ITIS and Features Inventory Support and Maintenance		$679,491	
Eliminate Contracted Improvements on ITIS		$250,000	
Improve Pavement Program Efficiency		$540,000	
Benefit of establishing enterprise platform for corporate assets		$800,000	
Benefit to Public of Improved Safety Data		$2,100,000	
Total Benefits		$6,074,757	$6,074,757
Project Payback - After Implementation			Less than 5 years

As the table above illustrates, ODOT will likely see a return on investment within five years after implementation. In addition to the approximately $6 million dollars worth of tangible benefits the TransInfo system is expected to deliver a large number of intangible benefits. The benefits derived will support the agency's asset management goals. From a strategic planning perspective, Asset Management will provide ODOT with the kind of information decision-makers need on a daily basis to manage a large and complex operation.

This analysis concludes that the project is both cost-effective and in line with agency goals. The Project Team recommends that the project move forward.

3. Cost and Benefits Report

3.1 Project Background

The primary objective of this project is to replace the Integrated Transportation Information System (ITIS) and the Features Inventory file with a linear asset management application that will provide a unified view of roads and their features for ODOT and other consumers of the data. This project will integrate ITIS, Features Inventory and Geographic Information Systems (GIS) functionality into a single system, and will create a foundation of roadway information on which other Asset Management (AM) systems can be built. This new system has been named "TransInfo".

Rather than build a system, the Agency has elected to select a vendor that can supply the COTS (commercial off-the-shelf) package that best meets the Agency's needs and supports the realization of the benefits, as described in the benefits section of this document. In addition to implementing the package, the project will develop and implement all relevant interfaces to external systems, reports and files and will adjust business processes as needed to maximize the benefits that can be gained by using the new system.

3.2 Purpose

The purpose of this report is to provide a high level overview of costs and benefits for implementing and maintaining a single system to replace ITIS and Features Inventory. Additionally, it briefly discusses the project risks that could have an impact on benefit realization.

This Costs, Benefits, and Risk report will be updated at the end of the System Architecture phase.

3.3 Definitions

Transportation Data Section (TDS) (Responsible for ITIS): The Transportation Data Section within the Transportation Development Division (TDD) collects, analyzes, integrates, and delivers data to statewide decision-makers to help support and prioritize Oregon's transportation needs and to satisfy federal reporting requirements. Data is analyzed and integrated for use by various program areas to assess current conditions, as well as provide statistics and measure performance of transportation facilities, programs, and systems. This information assists program managers in making the most efficient use of resources. This section includes multiple work units including Crash Analysis and Reporting, Geographic Information Services, Road Inventory and Classification Services and Transportation Systems Monitoring.

Road Inventory and Classification Services Unit (RICS) (Responsible for ITIS): The Road Inventory and Classification Services Unit is part of the Transportation Data Section. This unit is responsible for: development, maintenance and enhancement of ITIS; the federally required Highway Performance Monitoring System which is used in Congressional reports to monitor and analyze the overall condition of the national public road system; administration of the Functional Classification (FC) program, which is the collection and maintenance of road information necessary to classify and monitor the highways, roads, and streets within Oregon; the federally mandated Certified Mileage Report which is a factor in distributing certain federal funds providing mileage statistics. This unit is also responsible for the State Highway Video Log.

Geographic Information Services Unit (GIS) (Responsible for Transportation Framework): The Geographic Information Services Unit is part of the Transportation Data Section. This unit is responsible for: preparation of urban and rural transportation maps; Geographic Information System (GIS) analysis, products and data; custom maps, GIS and data products as requested. In addition this group represents ODOT on mapping and data uniformity issues with other governmental agencies.

Highway Program Office (HPO) (Responsible for Features Inventory): The Highway Program Office (HPO) within the Highway Division is responsible for Federal Funds programming; STIP / Financial Plan coordination; Maintenance Management Services; Financial Coordination and Highway Budget services; coordination of Highway Performance Management, Resource Planning and Data Warehouse programs; Legislative / business reporting for many of the Oregon Transportation Initiative Act (OTIA) projects; Connect Oregon implementation; Transportation Enhancement Program; and development of the Local Certification program.

Maintenance Management and Highway Budget Unit (Budget/MMS) (Responsible for Features Inventory): The Highway Budget and Maintenance Management System Unit, which are part of HPO, are tasked with the maintenance of the Features Inventory system, as well as development of the Highway Division Legislative and Operating Budget. This unit also monitors the implementation of the budget which includes cash flow and limitation forecasting, financial reporting, Legislative & OTIA reporting and trend analysis.

Asset Management: Asset Management is a systematic and strategic approach to maintain, upgrade, and operate physical assets, such as roadways, traffic control structures and bridges, in a cost-effective way. The Asset Management strategic approach, for the Oregon Department of Transportation (ODOT), means using the available resources to get the best possible results for the preservation, improvement, and operation of Oregon’s state-owned transportation infrastructure assets.

System Administrator: A system administrator is a business user with the authority and responsibility to manage system settings, look-up data, and configure business rules. It is not yet determined if the system administrator will be responsible for the assignment of system users and user roles.

Technical Administrator: A technical administrator is an information systems employee with the authority and responsibility to manage the backend system configuration and to guide/support the system administrator when data and rule configuration work is done. It is not yet determined if the technical administrator will be responsible for the assignment of system users and user roles.

Power Users: A power user is a person who is very knowledgeable of the processes in a business program and in the use of the business area’s information systems. This person typically provides administrative support to the system and works with systems on a daily basis.

Casual Users: A casual user may work in the business program area or may be a customer of the business program area and uses the associated systems infrequently or for reporting purposes only.

3.4 Document Organization

This analysis is based on known costs resulting from the contract award to Exor Corporation, budget figures available at the end of the Preliminary Analysis phase, a review of current systems costs, and estimated savings from cost avoidance and efficiency gains.

The approach for this report is to identify the known costs, tangible benefits, intangible benefits and risk factors of implementing a linear asset management system utilizing the following analysis categories:

Costs of Development*:* Costs associated with the build and maintenance of the new system. For financial analysis purposes, costs have been projected for a five year period, the number of years estimated to achieve a full return on our investment

Tangible Benefits: Benefits that are quantifiable as cost savings and cost avoidance after implementation of a system based on project requirements. These benefits are presented according to cost avoidance and cost savings provided through operating the recommended system.

Intangible Benefits: Benefits that cannot be quantified with a dollar value but will provide added value or have positive effects on the organization.

Risks and Contingencies: Those factors that will impact the organization's ability to implement the system at the estimated costs, or to realize the identified benefits.

4. Assumptions

Unless otherwise noted, costs and tangible benefits are calculated based on the following assumptions:

- The resulting application and database will be housed at the SDC.
- The system will be used annually by two part time business system administrators (one primary and one backup), approximately 10 power users and 10 to 15 casual users
- One new power user will be trained, on average, every other year (or 1/2 per year)
- The majority of build costs are spent by the end of the 2009 – 2011 biennium (ending June 30, 2011)
- The project will implement a solution by the end of September, 2010 (Variances from this schedule will impact cost).
- Build periods represent all years required to select and implement the new system. Ongoing costs and system benefits begin Year 1 (Sept, 2010), the first year of implementation
- Monthly state salaries are based on an assumed $50 hourly rate with 173.33 hours per month (includes salary, state-paid taxes and benefits)
- ODOT will discontinue the use of NOMAD tools, the ITIS application and the Features Inventory file/application
- Inflation is not factored into either costs or benefits. It is assumed the cost of inflation will be offset by inflation in the value of the benefits
- The hardware and software cost estimates represent all costs required to procure the software package and any hardware or additional software licensing required to deploy it

5. Costs of Development

5.1 Cost Assumptions

The costs represented below are based on the project budget as of the end of Preliminary Analysis (PA) Phase. These costs are assumed to be correct with a ***moderate***[1] confidence level**.** Recurring costs are roughly estimated for the first five years of use. No facilities costs are included due to the fact that the ODOT and SDC (State Data Center) facilities currently exist and any contractor (vendor) facilities used during analysis and development phases of the project will be provided by the contractors. Any cost associated with the use of contractor facilities included in the contract cost.

[1] Using the City of Portland Oregon, "Project Estimate Confidence Level Rating Index", the rating of moderate is based on:
- Project scope defined but lacks details.
- Project specifications incomplete (60%-70% design and engineering phase).
- Total Project contingencies (including project management, design, engineering, plus construction) may range between 30% – 40%.

5.1.1 Cost Estimates

TransInfo System Costs							
Project Costs	***Total Build Costs***	***Year 1***	***Year 2***	***Year 3***	***Year 4***	***Year 5***	***Total Build + 6 yrs Ownership Costs***
COTS Software Support							
System Architecture	$251,074	$ -	$ -	$ -	$ -	$ -	$251,074
Design/Construction	$422,256	$ -	$ -	$ -	$ -	$ -	$422,256
Implementation	$102,557	$ -	$ -	$ -	$ -	$ -	$102,557
Management & Tracking	$156,928	$ -	$ -	$ -	$ -	$ -	$156,928
Project Closure	$38,508	$28,014	$ -	$ -	$ -	$ -	$66,522
Enhanced Support	$ -	$55,000	$55,000	$55,000	$55,000	$55,000	$275,000
Staff & Contracted Personnel							
Information Systems Staff	$934,430	$18,000	$18,000	$18,000	$18,000	$18,000	$1,024,430
Business Staff	$790,330	$25,950	$25,950	$25,950	$25,950	$25,950	$920,080
DOJ / Data / Interface / Oracle / Project Mgmt.	$796,167	$ -	$ -	$ -	$ -	$ -	$796,167
Hardware Maintenance							
Operations Support (SDC)	$31,200	$31,200	$31,200	$31,200	$31,200	$31,200	$187,200
COTS Software Maintenance & Licensing							
TransInfo Software Licensing	$322,800	$ -	$ -	$ -	$ -	$ -	$322,800
TransInfo Software Maintenance	$ -	$102,219	$102,219	$102,219	$106,102	$114,934	$527,693
External Quality Assurance							
QA Assessments	$153,750	$ -	$ -	$ -	$ -	$ -	$153,750
Total System Costs	**$4,000,000**	**$260,383**	**$232,369**	**$232,369**	**$236,252**	**$245,084**	**$5,206,457**

5.1.2 Software/Hardware

Hardware and software costs are based on contract agreements with the vendor and the current SDC cost of services schedule. The figures represent all procurement costs, including the TransInfo software itself and any supporting hardware or software required to implement the new system.

5.1.3 Staff and Contracted Personnel

<u>Build Costs</u>

- Information systems staff estimates are based on the estimated number of hours required of ODOT staff analysts, developers, DBAs and technicians.

- Business staff estimates are based on an assumed full time business analyst, an actively involved system manager and the participation of Leadership Team members, Steering Committee members and subject matter experts.
- The contracted Project Manager estimates are based on a $71 hourly rate.
- Dept. of Justice and Contract Support costs are based on an average of $126 an hour.
- Data conversion contractor costs are based on a $70 hourly rate.

Maintenance Costs

- Ongoing information systems staff estimates are based on an average of 30 DBA hours of support per month. This includes the estimated effort required to work with the vendor for basic configuration changes, troubleshooting, new release installation, minor updates to system interfaces and testing.
- Ongoing business staff estimates are based on a single business system administrator assigned at 25% for each year subsequent to implementation (some of this time may be allocated to another administrator to provide a backup for the role). This includes the estimated effort required to maintain look up values, test new releases, and provide training when functionality is updated/changed/added.
- The contract with Exor provides for standard support and maintenance through May 2014. This amount has been prepaid and totals $247,786. For the 12 month period beginning June of 2014, standard support and maintenance from Exor will be $109,984. This document assumes an annual increase in this amount of 4.5%.
- Enhanced support from Exor will begin in 2011 at the rate of $55,000 per year. This document assumes an annual increase in this amount of 4.5%.
- Included in the support and maintenance costs is $200 per year from the start of the project for Third Party Escrow of COTS source code.

5.1.4 Hardware Maintenance

Hardware Maintenance estimates assume the TransInfo system will require 4 servers to support data retention and the move to a client server platform. These servers will provide three environments, development, system test, and production. Current SDC pricing includes up to 80 GB of storage with the support of one server. The current systems scheduled for replacement use well under 2 GB of storage space to date (including both production and development environments). For this reason, it is estimated that there will be no additional storage costs above the server maintenance.

Additionally, assuming disaster recovery backup of only current data, the TransInfo system will require less than 2 GB of increased backup storage. Based on the current SDC rates the additional ongoing hardware costs will be as follows:

SDC Costs						
	Rate	2009	2010	Totals at end of build	Totals of 5 Yrs of Ownership	Total Build + 5 yrs Ownership Costs
Application Server *	$648 per server per month	$5,832.00	$9,720.00	$15,552.00	$77,760.00	$93,312.00
Database Server *	$648 per server per month	$5,832.00	$9,720.00	$15,552.00	$77,760.00	$93,312.00
Disk Space	$4 storage per month	$36.00	$60.00	$96.00	$480.00	$576.00
Totals		**$11,700.00**	**$19,500.00**	**$31,200.00**	**$124,608.00**	**$187,200.00**

* Development Servers in place May 1, 2009 / Production Servers in place April 1, 2010

5.1.5 Software Maintenance and Licensing

TransInfo Software Licensing and Maintenance estimates are based on costs agreed to in the contract with Exor Corporation. Licensing is for 50 users for the database and application server and 10 users for Spatial Manager, ESRI licensing, and Schemes Manager. Included in the cost for the application and database server is the licensing cost for Oracle products being utilized in the implemented solution. Overall licensing is summarized below.

Exor Licensing	
	Cost
Exor Application Server - 50 Users	$ 176,000.00
Exor Database Server - 50 Users	$ 59,000.00
Exor 3rd Party Escrow Fee for 5 Years	$ 1,000.00
Spatial Manager - 10 Users	$ 80,000.00
ODOT ESRI Licening - 10 Users *	$ (16,000.00)
Schemes Manager - 10 Users	$ 22,800.00
Total	**$ 322,800.00**

**ODOT already has ESRI licensing which results in a $16,000 reduction to licensing needed from Exor.*

Application Maintenance is summarized in the table below.

Exor Application Maintenance	
	Cost
Exor Application Server - 50 Users for 3.5 years	$ 135,520.00
Exor Database Server - 50 Users for 3.5 years	$ 45,430.00
Enhanced Support and Maintenance	$ 109,980.00
Spatial Manager - 10 Users for 3.5 years	$ 61,600.00
ODOT ESRI Licening - 10 Users for 3.5 years	$ (12,320.00)
Schemes Manager - 10 Users for 3.5 years	$ 17,556.00
Total	**$ 357,766.00**

**ODOT already has ESRI licensing which results in a $12,320 reduction to licensing needed from Exor.*

5.1.6 Training and Transition

These costs include those associated with the training and institutionalization of the new system and related business processes. Business training and transition costs are related to the time and effort required to learn the new system and processes. It is assumed that this learning curve will not create additional costs, but will counteract the first six months of the productivity increase benefits (increased productivity for data management, increased productivity for reporting and reduced training).

5.1.7 External Quality Assurance

The estimate for external quality assurance is calculated based on approximately 5% of the project budget.

5.2 Sources of Funding

The TransInfo project costs are funded through a mixture of POP, Maintenance, TPD and TAD sources. Approximately 41% of the five year TransInfo costs are internal (state staff covered by base budget). The remaining 59% of the five year costs are external (software licensing / maintenance, contractors, etc.).

TransInfo Sources of Funding	
TPD	$ 3,082,027.00
POP	$ 1,000,000.00
Maintenance	$ 100,000.00
TAD	$ 1,024,430.00
Totals	***$ 5,206,457.00***

6. Benefits

6.1 Benefit Assumptions

Tangible benefits are quantifiable as cost savings and cost avoidance due to the implementation of the new system. Tangible benefits are assigned dollar amounts after applying assumptions and making calculations. Intangible benefits are based on the non-monetary advantages of deploying the system. These benefits have been identified because they are in support of department or organization goals, and set up the agency for future monetary savings that cannot currently be quantified.

6.2 Tangible Benefits

TRANSINFO SYSTEM TANGIBLE BENEFITS

COST REDUCTION	*Year 1**	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Lifecycle Total (6 Years)*
6.2.1 Increase productivity for data management	$108,004	$216,008	$216,008	$216,008	$216,008	**$972,036**
6.2.2 Increase productivity for Report and Query Writing	$43,444	$86,887	$86,887	$86,887	$86,887	**$390,992**
6.2.3 Reduce training time	$38,027	$76,053	$76,053	$76,053	$76,053	**$342,239**
6.2.4 Eliminate ITIS and Features Inventory support	$75,499	$150,998	$150,998	$150,998	$150,998	**$679,491**
6.2.5 Eliminate contracted improvement/maintenance projects on existing ITIS	$50,000	$100,000		$100,000		**$250,000**
6.2.6 Improve Pavement Program Efficiency	$60,000	$120,000	$120,000	$120,000	$120,000	**$540,000**
6.2.7 Benefit of establishing enterprise platform for corporate assets		$400,000		$400,000		**$800,000**
6.2.8 Benefit to Public of Improved Safety Data		$300,000	$600,000	$600,000	$600,000	**$2,100,000**
Total Benefits	**$374,973**	**$1,449,946**	**$1,249,946**	**$1,749,946**	**$1,249,946**	**$6,074,757**

* As noted in section 5.6.1, it is assumed that no benefits will be realized in the first six months of ownership due to a learning curve period.

6.2.1 Increase productivity for data management

Through the implementation of an up-to-date asset management system, ODOT can realize a significant productivity increase within the RICS, Budget/MMS and GIS units. This will be especially beneficial because each year, the amount of asset management data captured and maintained by ODOT increases. As time progresses, there will be more assets to manage (and/or more detail to maintain), more construction plans to track, and more reports will be required by external customers. Because the ODOT staff currently available to do this work is already working at capacity, it will quickly become necessary to postpone other important work, or to contract for help in order to continue to maintain asset data.

The following table is based on the estimated effort involved to conduct the most common data management activities within ITIS and Features Inventory. The costs are calculated according to the annual effort required of identified power users, and the percentage of their time spent on specific tasks (see appendix A). These hours are used to calculate cost according to a $50 hourly rate. The estimated improvement percentages are based on the conservative project measures as outlined in the objectives section of the Project Statement.

INCREASED PRODUCTIVITY FOR DATA MANAGEMENT

	Research Cost	Calcul-ations Cost	Data Entry Cost	Care and Feeding Cost	Total Cost	Estimated % Amount Reduction	Adjusted Cost	Benefit Amount
Contract Data Management	$33,888	$101,187	$68,556	$13,911	**$217,542**	15%	$173,086	**$44,455**
Field Data Management	$11,375	$0	$29,576	$4,550	**$45,502**	10%	$36,856	**$8,645**
Boundary Data Management	$21,884	$9,534	$3,033	$4,550	**$39,002**	15%	$29,284	**$9,718**
Other Data Management	$56,986	$0	$9,317	$120,038	**$186,341**	50%	$33,151	**$153,189**
Totals	**$124,133**	**$110,721**	**$110,483**	**$143,049**	**$488,385**		**$272,378**	**$216,008**

* Adjusted Cost = (Total Cost - Care and Feeding Cost) * (1-Estimated % Reduction)
Benefit Amount = Total Cost - Adjusted Cost

By improving productivity so dramatically, ODOT can not only delay the need to hire contracted support to complete the increased work load, but the RICS, Budget/MMS, and GIS staff will be able to use the time made available through productivity gains to improve data quality and complete future asset management projects (see 6.3.3).

Contract Data Management

The TransInfo project expects to reduce the time required to enter construction plan information by at least 15%. The RICS Unit currently inputs information from approximately 115 construction plans per year, with a technician extracting information from approximately seven sheets per construction plan.

Currently, this information must be gathered manually from the construction plan information and entered into ITIS in a tabular format. The GIS unit is then notified of the update and uses the same raw construction plan information to enter the spatial values for the same information into GIS. The new system will allow for the entry of such data using one interface, which will be capable of capturing the spatial data and then representing it in both spatial and tabular formats. This improvement will not only reduce the data management time required of both the RICS unit and the GIS unit, but will also reduce the chance of mistakes or inconsistent data entry between the two. In the future,, , the construction plan data can potentially be brought over in a digitized format, or entered utilizing data from CAD construction drawings. The result would significantly reduce input time and increase accuracy.

Field Data Management

An improved structure for storing field inventory data, single points of entry and standard Windows tools, is expected to reduce labor costs related to inputting and maintaining this data by at least 10%. The RICS Unit currently inventories approximately 2,010 miles of state highway annually. This inventory is duplicated using different criteria to support features inventory on an as needed basis. Furthermore, as the agency moves towards the collection of more detailed inventory information, the number of transactions required to manage that data will increase.

In addition, the TransInfo system will allow management of inventory work from the system itself. This will cut the planning time required and reduce errors. Such as, skipping highways in the inventory effort or the opposite, conducting duplicate inventories of highways.

Other Data Management

Other data managed within the system exists to support external reporting requirements and interfaces to other ODOT systems. This data is spread throughout the system and is often maintained with the support of external tools such as Excel. Additionally, because this data is created using largely manual methods of data capture, entry and validation, it is more difficult to maintain, report, and verify. A large amount of staff time is spent researching the validity of the data and fixing errors that occur during manual or complex processes. Because the current systems do not provide the quality controls and data entry tools offered by more current applications, the error rate is high and the trust in the data is low. This coupled with the fact that this data is used to support a large number of interfaces and other systems within ODOT, means a great deal of time is spent not only correcting errors, but proving that reported data is correct. Moreover, the tools for conducting such research and making corrections are limited within the application, requiring a significant increase in time spent sleuthing through the data.

Further, this is typically critical data, maintained at the direction of FHWA or OTC (Oregon Transportation Commission). Thus, a significant amount of time is spent on research and care and feeding to ensure the accuracy of the data. A system that will consolidate the data, simplify data entry, eliminate the need to use external tools and provide quality control to verify its accuracy could greatly reduce the time required to manage this data.

Care and Feeding

The current systems require a large amount of care and feeding that will be eliminated in an up-to-date Windows-based application. Activities such as duplicate data entry, checking downstream data to ensure data integrity, and following a complex non-intuitive process for data entry, will no longer be required. For example: The daily process of entering construction plan data into the system requires the user to make entries on up to 19 different screens. In some cases, multiple updates must be performed using the same screen as part of the same task, in that the user must use a screen, go out and do something else using a different screen, and then come back to the original screen, making additional entries, in order to complete the task. The user must know which screens must be used, and in which order the screens must be utilized. ITIS does not prompt users with information on which screen is to be used next in order to complete a specific task and users must have extensive knowledge about the structure of the existing database in order to access and manage the data.

Many of these improvements are expected due to the anticipated implementation of a modern application that follows Windows standards and employs a relational database. A number of data management requirements have been included in the Statement of Work to promote the selection of an application capable of eliminating these “care and feeding” activities. This will set a foundation for future asset data being added at a significantly lower cost. Benefit estimates assume that these care and feeding activities will no longer be necessary; therefore 100% of the related costs can be saved.

Furthermore, the elimination of these care and feeding activities can directly help reduce the amount of time spent on research. Many of the current research activities are done to track down inconsistencies and mistakes that are made during the complex data entry process. If the data entry process is less complex, the number of such inconsistencies and mistakes is likely to drop significantly.

6.2.2 Increase productivity for report and query writing

The current reporting options for getting data out of ITIS and Features Inventory are cumbersome and require custom programming and/or technical expertise within the business. Because the existing tools do not have built in reporting mechanisms, ODOT has had to export the data to reporting databases and spreadsheets to work with and report on the data. These databases and files require time to use and maintain. They also create an opportunity for mistakes as reports are not always generated from the original source of the data.

The following table is based on the estimated effort involved to create queries and reports using the existing systems. The costs are calculated according to the annual effort required of identified power users, and the percentage of their time spent on query writing, report writing and care and feeding (see appendix A). These hours are used to calculate cost according to a $50 hourly rate. The estimated improvement percentage is based on the conservative project measure as defined in the objectives section of the Project Statement.

INCREASED PRODUCTIVITY FOR REPORTING

	Report Writing Cost	Query Writing Cost	Care and Feeding Cost	Total Cost	Estimated % Reduction	Adjusted Cost	Benefit Amount
Reporting	$9,534	$71,069	$66,736	**$147,339**	25%	$60,452	**$86,887**
Totals	**$9,534**	**$71,069**	**$66,736**	**$147,339**		**$60,452**	**$86,887**

* Adjusted Cost = (Total Cost - Care and Feeding Cost) * (1-Estimated % Reduction)
Benefit Amount = Total Cost - Adjusted Cost

Reporting

The estimated savings to the RICS unit to query and report information is 25%. However, the actual savings is likely to be more because this number does not take into account the time spent learning how to use technical tools for reporting purposes. In addition, users currently expend an unknown amount of time developing their own local applications because the RICS Unit does not have the time or resources available to do all the requested reporting. Assuming the level of labor savings projected in this analysis, the RICS Unit would be able to better serve its customer base by providing additional products.

Care and Feeding

As with the care and feeding required for data entry, reporting requires similar intimate knowledge of the database structure. What's more, when the same data is reported out of ITIS, Features Inventory, and user generated access databases and spreadsheets, there is a high probability that the numbers will not match. In this case a good deal of research and data validation activities must occur, adding cost (and uncertainty) to the reporting effort.

6.2.3 Reduce training time

The current system is complex and cumbersome. It does not follow Windows standards, which are often already known by new employees, and it does little to automate the entry or use of data. The result is that the learning curve for a new data technician is approximately 18 months. Part of this includes learning about the many ways to work around problems related to how data is stored in the current system—data which the current system was not explicitly designed to handle.

The following table is based on the estimated effort involved to train a new system user. The estimates are for both the trainer and the trainee. The costs and benefits are calculated using the following assumptions:

- Training time for casual users can be reduced by 30% because the data and data sources can be more readily understood
- Training time for power users can be reduced to 6 months (or one third of the existing training period) due to the expected decrease in the required knowledge of technologies, data inter-workings and system workarounds.
- One power user will be trained, on average, every other year (this is represented in table as ½ the training effort per year)
- One quarter of the new employee's training time requires a trainer (formal training, hand-holding, questions, etc)

The costs are calculated according to the annual effort required to complete training (see appendix A). These hours are used to calculate cost using a $50 hourly rate. The estimated improvement percentage is based on whether the trainee needs to learn the entire system or only the data and processes.

REDUCED TRAINING COSTS SUMMARY

	Trainer Time	Trainee Time	Total Cost	Estimated % Reduction	Adjusted Cost	Benefit Amount
Power User Training	$19,500	$78,003	**$97,503**	66%	$33,151	**$64,352**
Casual User/Customer Training	$21,668	$17,334	**$39,002**	30%	$27,301	**$11,701**
Totals	**$41,168**	**$95,337**	**$136,505**		**$60,452**	**$76,053**

* Adjusted Cost = Total Cost * (1-Estimated % Reduction)
Benefit Amount = Total Cost - Adjusted Cost

6.2.4 Eliminate ITIS and Features Inventory support

Implementing TransInfo will completely replace two existing legacy applications, ITIS and Features Inventory. By completely replacing these applications, the business units currently using those applications will no longer have costs for them. Those costs include NOMAD licensing and ongoing support for ITIS and Features Inventory.

ELIMINATED ITIS AND FEATURES INVENTORY SUPPORT		
	License/ Support Costs	***Benefit Amount***
NOMAD License	$47,000	$47,000
ITIS Support	$103,998	$103,998
Totals	**$150,998**	**$150,998**

NOMAD License

Once conversion of data from ITIS to the new application has been completed, the NOMAD query tool will no longer be needed. According to the license and maintenance agreement put in place for one year starting in August of 2006, the elimination of this software will save the state approximately $47,000 annually. Additionally, ODOT will no longer be required to maintain NOMAD expertise. The savings tied to maintaining NOMAD expertise is represented in the Reduce Training Time benefit (see section 6.2.3) for business users, and the reduced FTE required for maintaining the new system.

ITIS Support

ODOT currently dedicates 1 FTE to the support of the ITIS database and application. The salary of 1 employee at an estimated $50 hourly rate can be saved with the purchase of a COTS package. This support includes both regular maintenance activities and minor upgrades and data management activities. These activities will be done by a business or technical administrator from within the application in the future. Support costs related to the maintenance of the COTS package can be found in the costs portion of this document.

Features Inventory Support

ODOT currently allocates approximately 60 hours annually to the support of the Features Inventory file and application. It is assumed that this time will likely be allocated to managing the interface between the new TransInfo system and the MMS system in the future. Therefore, no tangible support savings are expected for Features Inventory Support.

6.2.5 Eliminate contracted improvement/maintenance projects on existing ITIS/Features Inventory

Reporting requirements from external customers (such as the legislature and congress) undergo changes that must be implemented in the systems used within ODOT. Because these systems were built in the 70s and 80s, they do not have the benefit of data flexibility that is usually built into newer systems. ODOT must launch a maintenance effort to update the system each time new or modified data requirements are identified. A good number of these efforts are handled by the one dedicated FTE assigned to the ITIS system. However, the amount of work required to keep up with these modifications is more than can be accomplished by a single support person. Therefore ODOT hires a contractor, approximately once every two to three years, to work on the backlog of work requests. These contracts are typically set for $75,000 worth of work, and it can be assumed that the agency accrues at least another $25,000 in costs related to the contracted work (e.g. contract creation, contract management, business project involvement, etc).

COST OF CONTRACTED IMPROVEMENT/MAINTENANCE PROJECTS			
	Year 2	***Year 5***	***Benefit Amount***
Contract Costs	$75,000	$75,000	$150,000
ODOT Staff Costs	$25,000	$25,000	$50,000
Totals	**$100,000**	**$100,000**	**$200,000**

The project requirements stipulate that the new system will have a flexible data structure that allows ODOT to administer this type of data change from within the application. This will eliminate the need for much of this type of modification. There are also requirements around the vendor’s adherence to industry standards and mandates; it can be assumed that future releases of the software will include modifications to keep the product up to date in this respect. Furthermore, ODOT has contracted with the vendor to provide a set number of hours of custom programming to cover any additional required modifications (see Costs section 4.2.4). Any other changes that must be done to the interfaces can be done by the ODOT support staff (see Costs section 5.1.3).

6.2.6 Benefit to the Pavement Program Efficiency Due to Improved Data

Pavement deterioration is not linear and pavements do not deteriorate at the same rate. A given pavement tends to look good for a few years, and then cracking begins. The cracking rate gradually accelerates and eventually the pavement crumbles rather quickly. The optimum time to re-pave a highway is at the point just before the pavement starts to crumble. ODOT uses sophisticated software for performance modeling of pavement in order to improve forecasting of paving projects. The data used by this software comes from ITIS. Improved data from TransInfo will provide a benefit to the efficiency of the Pavement Program.

STIP constraints require that projects be identified about 5-6 years ahead of time. The cost of a typical paving job is $3,000,000 (20 lane miles X $150,000 per lane mile). With a life expectancy of 15 years, it is estimated that paving one year too soon costs $200,000 per average paving job.

Conversely, when paving a typical job 1 year too late, pavement deterioration in just one year could require another 2 inch lift of asphalt concrete to repair, at a cost of $50,000 per lane mile, resulting in a total cost increase of $1,000,000.

With an annual budget of $120 million, better and timelier data is expected to contribute at least a 0.1 % increase in program efficiency, which will yield an annual savings of $120,000.

IMPROVE PAVEMENT PROGRAM EFFICIENCY			
	Current Amount	***Estimated Reduction***	***Annual Savings***
Annual Pavement Budget	$120,000,000	0.10%	$120,000
Totals	**$120,000,000**	0.10%	**$120,000**

6.2.7 Benefit of Establishing an Enterprise Platform for Corporate Assets

By establishing an enterprise platform for corporate asset management, the TransInfo project is laying a foundation that will benefit other projects by reducing the costs that would otherwise be associated with developing stand-alone applications.

Asset Management is an organization-wide process that helps the Agency to make cost effective decisions. It requires a thorough accounting of the Agency's linear assets, ensuring that everyone has up-to-date information at their fingertips. The goal is to maximize the lifecycle of all the agency's varied linear assets: from guardrails to concrete beams, from rumble strips to bridge structures, from computers to buildings to landscaping and more.

ODOT has embraced Asset Management and will be implementing it in phases. The foundation of this effort is to deploy a comprehensive Linear Asset Management system that allows all the pieces (current and future) to be interconnected.

Specifically, ODOT would like to eventually tie the following Asset Management systems/activities into the foundational system:

- The automatic capture of inventory and construction plan data through automatic interfaces with other core ODOT applications to assure consistency between systems and reduce redundant work efforts.
- The inclusion of sign, signal, retaining wall, and drainage facility data as part of our core asset management data set.
- Significant data availability and well established processes for priority features within the road network. Such as, traffic structures, roadside barriers, wetlands mitigations, retaining walls, and interchange structures.
- The inclusion of the data and functionality of the Non-State Highway Functional Class Database into TransInfo.

Assumptions

We are making the assumption that over the next several years, ODOT will be incorporating one additional application per biennium into the TransInfo platform. It is assumed that each new application would cost an average of $400,000 to build from scratch. The cost savings for each of these applications will average $400,000 due to the corporate asset management platform already have been established.

6.2.8 Benefit to the Public of Improved Safety Data

Several ODOT database applications that utilize TransInfo data use the data in “Trade-off” analyses to identify where to use limited funds to make the highway network safer. More accurate and timely TransInfo data will contribute to a safer highway network for the traveling public as the agency will be better able to direct its resources to optimize safety. Conservative estimates from ODOT's Traffic Engineering section, are that for every one million dollars, appropriately invested, the safety program will provide the traveling public one less serious injury or fatal crash every year.

Further, the Traffic Engineering section states, "Improving roadway inventory data for use in the new safety methods soon to available from AASHTO might produce as much as a 10-20% improvement in savings of serious injury or fatal crashes for every million dollars spent. Even with a 10% improvement and a typical investment of 30 million per year we would be saving 3 serious injury or fatality crashes equating to about a 3 million dollar savings per year to the public not to mention the pain and suffering."

TransInfo will be ODOT's corporate data source for highway network data and will be the cornerstone for improved roadway inventory data. Using the savings to the public as stated above and applying an even more conservative figure of 2% , we estimate that TransInfo will provide a savings to the public of $600,000 per year. For this analysis, we are expecting half of this amount in the second full year of system operation and the full $600,000 in each following year.

6.3 Intangible Benefits

6.3.1 Increased detail for field inventory management

The Features Inventory file provides data for planning and budgeting ODOT maintenance activities. The feature counts in the Features Inventory System are used as a factor when determining the ODOT highway maintenance budget. Having an accurate inventory is critical in order to gain the funding necessary to maintain the highways and infrastructure at an agreed-upon level of service. The new system will provide the tools required to capture a more detailed set of inventory data that is more closely tied with other linear asset data within ODOT. The benefits of such an improvement are to:

- Provide a more accurate record of where assets are located on the network. Currently, the features information is inventoried by 10 mile highway segments and then summarized in total for each Maintenance crew. The new system will be able to capture the exact location of the asset and it's relation to other assets on the roadway.
- Improve reporting to enable more concise planning and management of assets, supporting an increase in proactive planning and management of assets.
- With increased accuracy of asset locations, the effort to verify asset inventory will be significantly reduced. A current estimate for one ODOT district is that with the increased detail of inventory data, the effort to verify field inventory will be reduced 50-60%. For that district, a yearly inventory verification for takes 200 hours. With TransInfo, this district expects to reduce that effort to 80 to 100 hours. Procedures vary significantly among the districts making a state-wide estimate of similar savings difficult.

6.3.2 Increase time available to improve existing data and processes

ODOT's strategic approach to asset management is to use available resources to get the best possible results for the preservation, improvement and operation of Oregon's transportation infrastructure assets. In light of this effort, the amount of asset information and level of detail needed is steadily increasing. Currently, the staff available to do this work is already working at capacity. However, given the level of productivity savings discussed in this document, ODOT will be able to apply existing staff to complete work that has already been set aside because there isn't enough time to complete it. Such work includes:

- Pulling additional data from construction plans beginning with the implementation of DFMS, roadside barrier and Bicycle/Pedestrian projects done in summer 2008 (requiring an additional 15 min to 1 hour per plan)
- Increasing data validation and quality assurance activities
- Reviewing historic construction plan data and ensure the data is correctly entered
- Researching and entering data "as constructed" (where the "as constructed" information differs for the originally entered plan)

- Conducting a detailed boundary review (with specific attention to city limits)
- Filling in missing Right of Way map numbers
- Providing more customer outreach and training, including in-person visits to region and district offices
- Assisting other Linear Asset Management groups in starting up inventories
- Increasing Straightline Chart production
- Preparing and providing new template reports on TransViewer

6.3.3 Improve/create/replace interfaces with other ODOT systems

The ITIS and Features Inventory systems are ODOT's primary repositories for ODOT's core LRS (highway and milepoint) system and asset information.

Due to the nature of the data stored in these systems, the more the data can be structured as a corporate data source and used to support other ODOT applications, the more coherent our data management and reporting can be. Among other things, this project will lay the groundwork to tie other systems into one common LRS and set of geometry representing the state highway system.

Currently, the data stored in these systems comes from several sources. While most of these sources are currently manual, there are many that could be automated with the proper integration.

Further, the data stored in ITIS and Features Inventory is used to support several systems through a combination of automated interfaces, electronic extracts, manual activities and reports. The LRS is distributed and maintained manually in many of ODOT's Asset Management systems. The new system is expected to more efficiently support such interfaces and provide the tools and structure needed to increase the level of automation involved in these interfaces.

6.3.4 Share knowledge and effort with other agencies

As many state, federal and local agencies are now active in implementing asset management in their day-to-day activities, it is important to consider strategies that emphasize communication and the sharing of information.

By selecting a COTS package that is already in use by transportation agencies in other states, Canadian provinces and large municipalities, ODOT will have the opportunity to participate in partnerships and user groups. These connections are likely to:

- Provide valuable lessons learned on both the implementation of such a product and the way to get the most out of it once deployed
- Bring to light potential uses of the system and efficiencies to be gained
- Allow for the sharing of enhancements or scripts
- Lend weight to requests made of the vendor, and allow ODOT to benefit from vendor updates done at the request of another agency

6.3.5 Reduced risk to ODOT crews and public travelers due to consolidated field efforts

Employee and Public Safety

Currently field inventory is accomplished by various crews throughout the state. Every effort is made to ensure employee and public safety while our crews are on the road. However accidents do occasionally happen to field inventory staff or members of the traveling public. It is ODOT's intent to streamline field inventory efforts and reduce the frequency and duration of data collection along the roadway. Combining the ITIS and Features Inventory data into one system will allow the impacted work units to better coordinate field inventory activities. Over time, this will result in a decrease in the number of trips to the field to collect or verify data. If a COTS package with an automated field data collection module is selected, this would further streamline field collection efforts and reduce the amount of time needed to collect data in the field.

Supporting Safety Programs

ITIS data is also used to support new data and reporting requirements of the Federal Safe, Accountable, Flexible, and Efficient Transportation Equity Act (SAFETE_LU) such as determining high crash locations on highway segments with low traffic volume and low federal functional classification. ITIS also provides data to calculate several Oregon Key Performance Measures, many of which are related to safety such as:

KPM#1	**Traffic Fatalities: Traffic fatalities per 100 million Vehicle Miles Traveled (VMT) (ITIS provides AADT and centerline mileage needed to calculate State Highway VMT)**
KPM#2	**Traffic Injuries: Traffic injuries per 100 million Vehicle Miles Traveled (VMT) (ITIS provides AADT and centerline mileage needed to calculate State Highway VMT)**
KPM#6	**Large Truck At-Fault Crashes: Number of Large Truck At-Fault Crashes per 100 million Vehicle Miles Traveled (VMT) (ITIS provides AADT and centerline mileage needed to calculate State Highway VMT)**
KPM#15	**Pavement Condition: Percent of pavement lane miles rated "fair" or better out of total lane miles in the state highway system. (ITIS provides pavement data and lane miles)**
KPM #16	**Bridge Condition: Percent of state highway bridges that are not deficient. (ITIS provides base milepoint location)**
KPM#19	**Bike Lanes and Sidewalks: Percent of urban state highway miles with bike lanes and pedestrian facilities in "fair" or better condition. (ITIS provides highway miles, urban designation, and location and condition of bicycle and pedestrian facilities.)**

This project will increase ODOT's ability to respond to the ever changing needs of various safety programs through better data accuracy, increased ability to produce both tabular and map based reports, and the option to quickly add new fields to the database to track additional data as needed.

6.3.6 Improved/Faster reports for external customers

Through this effort, ODOT will be able to provide data that is quickly accessible, more comprehensive, and solidly defensible to each of the following customers through enhanced reporting functionality and increased accuracy of the captured data.

State Legislature

- ITIS reports help Oregon legislative committees make informed transportation policy and funding decisions.
- The formula to distribute the $500,000 of state gas tax dollars incorporates mileage figures from the ITIS database.

US Congress

- Federal-aid highway funds come to Oregon through a variety of programs using formulas which include road mileage data.
- Lane miles of principal arterial roads are a factor in the apportionment formula used to determine funding allocations for the National Highway System Program.
- Lane miles on interstate routes are a factor of the apportionment formula used to determine funding allocations for the Interstate Maintenance Program.
- Total lane miles of Federal-aid highways are a factor in the apportionment formula for the Surface Transportation Program.
- Road mileage figures that originate from the ITIS database influence 60% of the average annual apportionment (268 million in federal financial year 2007) which Oregon expects to receive for Federal-aid Highways.

FHWA (Federal Highway Administration)

- FHWA receives Oregon road data to monitor and report to Congress in the form of federal data submittals (e.g., HPMS, NBI, HERS). Each submittal is built using information from ITIS to meet federally mandated submittal guidelines, and could result in financial penalties if not submitted on time or accurately.

FEMA (Federal Emergency Management Administration)

- During emergency situations such as flooding, FEMA uses Federal Functional Classification data from ITIS to determine the federal aid status of roads and bridges.
- Having this data readily available means that funding decisions for needed repairs can be made immediately following a major disaster.

Utilities

- ITIS data is used by utility companies (e.g., PGE, NW Natural, Century Telephone, Pacific Fiberlink, etc.) to apply for permits, and determine the location of obstructions and physical characteristics of the road. Additionally, improved information as to the location of the physical characteristics could reduce construction problems for the utilities.

Although this benefit is not currently tangible, it is probable that improved detail, quality control, and reporting capabilities will contribute to ODOT's continued ability to obtain the level of funding currently assigned us by such governmental bodies.

6.3.7 Improved Project Scoping

Before projects are added to the State Transportation Improvement Project (STIP) list, ODOT staff must inventory the physical features of the roads that will be worked on. This information is used to ensure that issues that could delay or impact the cost of the project are known and dealt with up front.

Project requirements differ depending on the type of funding used. For example, work that significantly alters the roadway prism (such as modernization or safety projects) requires an extensive field inventory to determine the location and cost of addressing certain physical features. Even preservation paving projects require a detailed field inventory to determine the cost of maintaining minimum curb heights, guardrail and sidewalk ramps, as well as any required drainage facility work. Projects that are required to include extensive work on these physical features can cost two to three times more than other projects.

It is critical to ODOT project planning and budgeting that staff have access to accurate and up to date information when planning for these construction projects. Today, staff begins by collecting what data they can in the office, then conducting field inventories to verify the data. Increased accuracy, faster data update cycles, and consolidated inventory systems will all help to increase staff's trust of the existing data, and will over time reduce the number of scoping field trips that are required.

7. Risks and Contingencies

The identified risks measure the likelihood of completing the project within the projected cost and actually attaining estimated benefits. These risks listed are from the Quality Assurance report at the end of the Preliminary Analysis phase.

Risk # 1	**Schedule.** Schedule is highly reliant on a State RFP/Contract process that has been rampant with delays
Mitigation # 1	• Holding progress meetings with the State Procurement Office (SPO) • Advocated with SPO and DOJ for increased priority of work • Adjusted project schedule to reflect current situation • Moving portion of funds to next biennium
Risk # 2	**IS Resource Skill.** IS resources may not possess the right combination of skills and abilities to meet vendor requirements.
Mitigation # 2	• Adjusted team composition based on Human Resources Plan skill / ability review • Reviewing COTS vendor skill / ability requirements • Adding additional IS resources to project team
Risk # 3	**Stakeholder Responsibility / Involvement.** Some stakeholder units are unclear about what their level of responsibility and involvement will be as the project progresses.
Mitigation # 3	• Communicating next step tasks with stakeholders • Involving stakeholders in vendor meetings as appropriate • Meeting key stakeholder units to identify concerns and develop ways to address
Risk # 4	**Business Process Change.** The level of business process changes may be underestimated both in terms of actual work and in terms of who will be impacted.
Mitigation # 4	• Scheduling meetings with impacted units to explain / discuss changes • Developing follow-up strategy

7.1.1 Risk Assessment

Members of the project leadership, used the RAM project risk assessment tool to quantify project risk at the System Architecture phase of the project. The ODOT Risk Assessment Model is a tool used to identify project areas that may warrant careful monitoring. RAM provides project managers the opportunity to identify areas that, if carefully monitored and managed, should improve the likelihood of success.

Using this tool, leadership members answered questions about the project and the tool provided the following scoring:

Risk Type	Score	Status
Strategic Risk	1.29	●
Financial Risk	2.17	●
Project Management Risk	2.00	●
Technology Complexity and Risk	1.71	●
Business Complexity and Risk	2.20	●

This tool categorizes the scoring as follows:

Status Categories	
1.0 - 4.0 Low Risk	
4.0 - 7.0 Medium Risk	
7.0 - 9.0 High Risk	

The TransInfo project is currently at low risk of not completing the project scope within projected cost and actually attaining estimated benefits.

8. Analysis and Recommendation

The project budget is estimated at $4 million dollars over the build period, and the total cost of build plus five years of ownership is just over $5.2 million. The projected benefits over five years of ownership are estimated at over $6 million. This indicates that ODOT will likely see a return on investment within five years of implementation.

Furthermore, there are a large number of intangible benefits to be realized through this effort - one of which is tied to the department's goal to improve safety, and another is tied to the department's ability to respond to federal and state requirements. As the foundation for an Asset Management solution, numerous other projects have been identified which rely upon this base. Those future projects will provide ODOT with benefits far in excess of what can be addressed in this document. From a strategic planning perspective, Asset Management will provide ODOT with the kind of information decision-makers need on a daily basis to manage a large and complex operation.

This analysis concludes that the project is both cost-effective and in line with agency goals. The Project Team recommends that the project move forward.

Appendix 'A'

The following charts provide the detailed calculations behind the anticipated benefits stated for increased productivity for data management (topic 6.2.1), reporting (topic 6.2.2), and training time (topic 6.2.3). Calculations based on a loaded monthly salary of 50*173.33 ($50 hourly rate * 173.33 standard number of hours per month). Total Cost calculations are based on the loaded monthly salary times the effort (months).

INCREASED PRODUCTIVITY FOR DATA MANAGEMENT
Contracts Data Management

	Loaded Monthly Salary	Effort (Hours)	Effort (Months)	Research Percent	Research Cost	Calcul-ation Percent	Calcu-lation Cost	Data Entry Percent	Data Entry Cost	Care and Feeding Percent	Care and Feeding Cost	Total Cost
1	$8,667	606.66	3.5	50.00%	$15,167	25.00%	$7,584	10.00%	$3,033	15.00%	$4,550	$30,335
2	$8,667	3743.93	21.6	10.00%	$18,721	50.00%	$93,604	35.00%	$65,523	5.00%	$9,360	$187,207
Totals		**4350.59**	**25.1**		**$33,888**		**$101,187**		**$68,556**		**$13,911**	**$217,542**

INCREASED PRODUCTIVITY FOR DATA MANAGEMENT
Contracts Data Management

	Loaded Monthly Salary	Effort (Hours)	Effort (Months)	Research Percent	Research Cost	Data Entry Percent	Data Entry Cost	Care and Feeding Percent	Care and Feeding Cost	Total Cost
1	$8,667	909.98	5.25	25.00%	$11,375	65.00%	$29,576	10.00%	$4,550	$45,502
Totals		**909.98**	**5.25**		**$11,375**		**$29,576**		**$4,550**	**$45,502**

INCREASED PRODUCTIVITY FOR DATA MANAGEMENT
Boundary Data Management

Classification	Loaded Monthly Salary	Effort (Hours)	Effort (Months)	Research Percent	Research Cost	Calculation Percent	Calculation Cost	Data Entry Percent	Data Entry Cost	Care and Feeding Percent	Care and Feeding Cost	Total Cost
1	$8,667	519.99	3	40.00%	$10,400	35.00%	$9,100	10.00%	$2,600	15.00%	$3,900	$26,001
2	$8,667	86.67	0.5	65.00%	$2,817	10.00%	$433	10.00%	$433	15.00%	$650	$4,334
3	$8,667	173.33	1	100.00%	$8,667	0.00%	$0	0.00%	$0	0.00%	$0	$8,667
Totals		**779.99**	**4.5**		**$21,884**		**$9,534**		**$3,033**		**$4,550**	**$39,002**

INCREASED PRODUCTIVITY FOR DATA MANAGEMENT
Other Data Management

	Loaded Monthly Salary	Effort (Hours)	Effort (Months)	Research Percent	Research Cost	Data Entry Percent	Data Entry Cost	Care and Feeding Percent	Care and Feeding Cost	Total Cost
1	$8,667	2686.62	15.5	25.00%	$33,585	5.00%	$6,717	70.00%	$94,037	$134,339
2	$8,667	1039.98	6	45.00%	$23,401	5.00%	$2,600	50.00%	$26,001	$52,002
Totals		**3726.6**	**21.5**		**$56,986**		**$9,317**		**$120,038**	**$186,341**

INCREASED PRODUCTIVITY FOR REPORTING

	Loaded Monthly Salary	Effort (Hours)	Effort (Months)	Report Writing Percent	Report Writing Cost	Query Writing Percent	Query Writing Cost	Care and Feeding Percent	Care and Feeding Cost	Total Cost
1	$8,667	1559.97	9	10.00%	$7,800	20.00%	$15,601	70.00%	$54,602	$78,003
2	$8,667	346.66	2	5.00%	$867	70.00%	$12,134	25.00%	$4,334	$17,334
3	$8,667	346.66	2	5.00%	$867	60.00%	$10,400	35.00%	$6,067	$17,334
4	$8,667	693.32	4	0.00%	$0	95.00%	$32,935	5.00%	$1,733	$34,668
Totals		**2946.61**	**17**		**$9,534**		**$71,069**		**$66,736**	**$147,339**

REDUCED TRAINING TIME

	Loaded Monthly Salary	Effort (Hours)	Effort (Months)	Process/ Data Training Percent	Process/ Data Training Cost	System Training Percent	System Training Cost	Total Cost
Casual User Trainer	$8,667	433.33	2.5	100.00%	$21,668	0.00%	$0	$21,668
Casual User Trainee	$8,667	346.66	2	100.00%	$17,334	0.00%	$0	$17,334
Power User Trainer	$8,667	779.99	4.5	60.00%	$23,401	40.00%	$15,601	$39,002
Power User Trainee	$8,667	3119.94	18	60.00%	$93,604	40.00%	$62,402	$156,006
		4679.92	**27**		**$156,006**		**$78,003**	**$234,009**