

Application of Cross-Asset Optimization in Transportation Asset Management: A Survey of State Practice and Related Research

Requested by

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The Caltrans Division of Research and Innovation (DRI) receives and evaluates numerous research problem statements for funding every year. DRI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field.

Executive Summary

Background

Caltrans is investigating the business practice of transportation asset management (TAM). The department has a particular interest in the current state of the practice for using cross-asset, or multi-objective asset, optimization to prioritize projects and identify resource needs across assets, functions and goals.

To aid in this effort, this Preliminary Investigation presents the results of an investigation of the TAM-related processes of other state departments of transportation (DOTs) and an examination of completed and in-process domestic and international research that addresses the current state of the practice in applying cross-asset optimization in TAM.

Summary of Findings

We gathered information in five topic areas:

- National Guidance.
- State Practices.
- Related Research.
- Research in Progress.
- Vendors.

Following is a summary of findings by topic area.

National Guidance

- A 2011 AASHTO guide focuses on tools, systems and data associated with TAM.

- Case studies of successful state DOT TAM programs, including programs in Oregon and Utah that are addressing cross-asset optimization, are included in a 2010 Federal Highway Administration (FHWA) report.
- A 2009 FHWA case study examines New Jersey DOT’s decision-making tool used to develop investment options for transportation categories based on goals, objectives and performance measures.
- Enhancing a bridge management tool with multi-objective optimization is the subject of a 2007 NCHRP report.
 - A 2012 AASHTO memo describes plans for enhancing Pontis, AASHTO’s bridge management system, with a multi-objective analysis at the bridge, program and project levels.
- Establishing TAM performance measures and setting targets are the focus of a 2006 NCHRP report.
- National committees sponsored by AASHTO and FHWA seek to further the state of the practice of TAM and serve as a forum to discuss TAM-related issues.

State Practices

This section highlights activities related to cross-asset optimization in eight state DOT TAM programs. Included are conference presentations, research reports, strategic plans and other documents supporting the agencies’ TAM programs as well as a summary of interviews with representatives from six of the eight agencies.

The table below summarizes interviews with representatives from six state DOTs—Colorado, New Jersey, North Carolina, Ohio, Texas and Utah.

Cross-Asset Optimization in State DOT TAM Programs				
State	Program Status	Asset Categories	Tools	Future Plans
Colorado	Eight months into the yearlong development of a cross-asset optimization tool A system-level rather than project-level tool	Pavement Bridge Maintenance level of services Fleet and equipment Intelligent transportation systems Buildings	Deighton dTIMS Pontis SAP	Continue bringing all asset categories into dTIMS
New Jersey	Systems permit project-level optimization within each asset category; no optimization across categories	Bridge Pavement Safety Mobility Multimodal Support facilities Mass transit Capital program delivery Aviation	Deighton dTIMS Pontis	Seek input on how to conduct cross-asset optimization across asset categories; no timeline established

Cross-Asset Optimization in State DOT TAM Programs				
State	Program Status	Asset Categories	Tools	Future Plans
North Carolina	Completing deployment of bridge management system this year Waiting to implement full optimization until systems for all primary asset categories are implemented	Maintenance management Pavement Bridge Mobility	AgileAssets	Complete full cross-asset optimization within and across asset categories, and at the project and system levels, by January 2013
Ohio	Optimization limited to pavements at the system level	Pavement Bridge Culvert	Deighton dTIMS	Develop prototype to permit cross-asset optimization at system level across three asset categories
Texas	To date, relatively little focus on cross-asset optimization	Pavement Bridge	Plans to purchase commercial pavement TAM system	Develop model that addresses capacity versus maintenance
Utah	Cross-asset optimization at project level in process for pavement, bridge and safety assets; system-level optimization already in place	Pavement Bridge Safety Signs Mobility	Deighton dTIMS Pontis In-house safety database	Within five years, develop a comprehensive program that allows for optimization across all asset categories at the project level

- Florida and Oregon DOTs have also been active in considering cross-asset optimization.
 - A 2011 report documents enhancements to models contained in Florida DOT’s bridge management system that include multi-objective optimization.
 - While representatives from Oregon DOT were unable to provide additional details for this report, documents from the agency’s asset management web site indicate that cross-asset optimization is part of Oregon DOT’s comprehensive TAM strategy.
- North Carolina DOT will meet soon with representatives from New York State DOT who are considering implementation of cross-asset optimization beginning with a cross-asset optimization tool.

Related Research

Domestic

- A 2011 conference paper examined efforts by state DOTs in setting performance goals and budgets based on system tiers and the impacts of those tiers on pavement and asset management systems.
- A review of the literature and current practice in cross-asset management are the subjects of a 2010 TRB Annual Meeting paper.
- A 2009 FHWA report produced in collaboration with Purdue University describes the development of a novel project selection framework formulated as a multi-objective optimization problem.

International

- A 2009 TRB Annual Meeting paper describes a Canadian case study of cross-asset optimization of mixed assets over a very long term (20+ years).
- Guidance for the application of an analytic hierarchy process (AHP) as a decision support tool in road asset management is provided in a 2007 AUSTRROADS publication.

Research in Progress

- An NCHRP project expected to conclude this summer is developing performance objectives and measures of effectiveness for use in optimizing resource allocation across asset categories.
- The current state of the practice of TAM in state DOTs is the topic of an NCHRP synthesis. This synthesis will examine and summarize changes made or planned to apply TAM practices within and across all asset classes.
- A TxDOT project is investigating fair division algorithms as a mechanism for allocating funds and resources among competing interests.

Vendors

This section includes links to the web sites of the following vendors providing software and services for some of the state DOT TAM programs cited in this report:

- AgileAssets Inc.: Provides asset management systems and optimization tools used by North Carolina DOT; future use by New York State DOT.
- Deighton Associates Limited: Provides asset management systems and optimization tools used by Colorado, New Jersey, Ohio and Utah DOTs.
- Mandli Communications Inc.: Provides an interactive software environment that works with photolog images and data collected by Utah DOT.
- SAP: Provides resource planning tools used by Colorado DOT.

Gaps in Findings

Interest in cross-asset optimization is burgeoning, but our research indicates that a state DOT has yet to complete a comprehensive implementation of cross-asset optimization within and across all asset categories at both the system and project levels. It appears that North Carolina and Utah DOTs are at the forefront of cross-asset optimization among state DOTs. North Carolina plans to fully implement cross-asset optimization within and across three asset categories by January 2013. Utah DOT has a timetable for comprehensive implementation of cross-asset optimization across five asset categories within five years. Lessons learned from these implementations can inform other agencies' implementation efforts.

It is not clear which approach is most effective in implementing cross-asset optimization, though most agencies appear to be taking a bottom-up approach—fully implementing management systems for individual assets before optimizing across assets (as with North Carolina and Utah DOTs). Other agencies, such as New York State DOT, appear to be investigating a top-down approach that begins with implementation of an optimization tool.

Representatives from Oregon DOT were unavailable to contribute to this report. Documentation from the agency's web site indicates that cross-asset optimization is part of its overall TAM strategy.

Next Steps

Caltrans might consider the following in its evaluation of cross-asset optimization:

- Contacting agencies with robust TAM programs and plans in place to fully implement cross-asset optimization, including North Carolina and Utah DOTs.
- Consulting with Colorado DOT to learn more about its focus on optimizing across systems rather than projects.
- Contacting an agency such as New York State DOT that is beginning its evaluation of cross-asset optimization.
- Contacting Ohio DOT to learn more about the prototype in development to optimize across asset categories.
- Examining the results of an NCHRP project expected to conclude this summer that identifies and assesses optimization objectives and criteria.
- When representatives become available, consulting with Oregon DOT to learn more about that agency's approach to implementing cross-asset optimization.

Contacts

During the course of this Preliminary Investigation, we spoke to or corresponded with the following individuals:

State Agencies

Colorado

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National Guidance

AASHTO Transportation Asset Management Guide: A Focus on Implementation, American Association of State Highway and Transportation Officials, January 2011.

Publisher's information available at https://bookstore.transportation.org/Item_details.aspx?id=1757

This guide, which provides background information about TAM and its advantages, is presented in three parts:

- Part 1 focuses on organizing and leading TAM.
- Part 2 focuses on processes, tools, systems and data.
- Appendices include examples of asset management plans and four in-depth case studies of local and international agencies' experiences in implementing TAM.

Beyond the Short Term: Transportation Asset Management for Long-Term Sustainability, Accountability and Performance, Federal Highway Administration, Report No. FHWA-IF-10-009, 2010.

http://www.fhwa.dot.gov/asset/10009/tam_topr806.pdf

Included in this report are case studies of successful asset management programs across the United States and internationally. Among the programs examined are:

- **Oregon DOT.** The agency's 2006 Asset Management Strategic Plan set three goals:
 - Develop and implement a robust asset management data collection and storage system that is consistent, unduplicated, understandable, reliable and accurate.
 - Develop and implement a fully automated, flexible and complete asset management data reporting system that performs cross-asset analysis.
 - Develop and implement an integrated, usable and reliable asset management system that provides information and analysis for life-cycle cost management of assets so that funding allocation decisions are broad-based across various asset categories.

Other activities related to a cross-asset analysis include an initiative to review data from the current management systems to determine if they could be employed in the cross-asset analysis. A data improvement plan was developed for each priority class of asset.

- **Utah DOT.** An asset management database was developed "to facilitate optimizing both within various asset categories but also to allow for the first steps toward cross-asset optimization and tradeoff analysis."

Management Systems: Driving Performance—A Glance at Data-Driven Decisionmaking Practices, Transportation Asset Management Case Studies, Federal Highway Administration, July 2009.

<http://www.fhwa.dot.gov/asset/if09021/hif09021.pdf>

This case study about the application of management systems for planning and programming includes a discussion of New Jersey's Statewide Capital Investment Strategy (SCIS), a decision-making tool used to develop investment options for transportation categories based on goals, objectives and performance measures.

Categories examined by the SCIS tool include bridges, road, mass transit, airports, safety, congestion, multimodal, transportation-support facilities and local support. The SCIS shows the total infrastructure and other investment needs associated with each category and establishes 10-year target annual investment levels for each category based on predicted revenue levels. SCIS has the ability to link the selection of projects for capital funding with broad program objectives.

Multi-Objective Optimization for Bridge Management Systems, *NCHRP Report 590*, 2007.

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_590.pdf

This research effort sought to improve bridge management system (BMS) tools that focus on selecting a least long-term cost solution to function as a multi-objective optimization model.

Researchers developed two BMS optimization models: a network-level model and a bridge-level model. The network-level model provides a decision-making tool that optimizes bridge actions for multiple performance criteria, including cost, condition, risk, highway bridge replacement and rehabilitation program eligibility, and bridge health index. The bridge-level model evaluates the effect of bridge action alternatives on life-cycle cost and other performance criteria to selecting projects that are consistent with network goals. The models can operate independently or in tandem. The Multi-Objective Optimization System developed in this study could be deployed as an add-on to Pontis or integrated into the database.

Related Resource:

AASHTO Pontis 5.2 Cooperative Software Development Project Proposal, Memorandum, AASHTO, March 8, 2012.

<http://www.aashtoware.org/Documents/Project%20Proposal/AASHTO%20Pontis%205.2%20Project%20Solicitation%20Package%20FINAL.pdf>

This AASHTO memo solicits member agencies to participate in a project to develop the next generation of the Pontis Bridge Management System, which will incorporate risk assessments, multi-objective optimization and new deterioration models for more efficient planning and resource allocation.

See page 26 of the PDF (page 3 of the Pontis 5.2 Project—Work Plan) for “2.1.4 Task TM 4 Multi-Objective Analysis with Utility Function.” The new version of Pontis will have “the ability to incorporate a multi-objective analysis approach at the bridge, program, and project levels. Utility functions representing a wide array of factors of various importance/weights will be deployed to help represent the multiple objective goal.”

Performance Measures and Targets for Transportation Asset Management, *NCHRP Report 551*, 2006.

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_551.pdf

Volume II of this report introduces a framework for identifying performance measures and setting target values, primarily for highway infrastructure assets; appendices contain examples of performance measures and targets. The authors note that performance measures and target values are critical to the principles of asset management to analyze trade-offs, make investment decisions and monitor intended effects.

National Organizations and Associations

AASHTO Subcommittee on Asset Management

<http://tam.transportation.org/Pages/default.aspx>

The mission of this subcommittee of AASHTO’s Standing Committee on Planning is to advance the state of the practice of TAM. Resources available at <http://tam.transportation.org/Pages/Resources.aspx> offer TAM-related materials in the areas of asset management 101, innovation and success, management systems, tools, applications, AASHTO, TRB, and research and education.

Transportation Asset Management Expert Task Group (TAM ETG)

<http://www.fhwa.dot.gov/asset/etg/index.cfm>

Newly formed by FHWA's Office of Asset Management, the TAM ETG will serve as a forum to discuss changes in the way highway agencies are managing assets. Among other initiatives, the TAM ETG will:

- Outline a framework for financially sustainable transportation infrastructure that clarifies connections among asset management, stewardship, risk management, performance management and long-term financial planning.
- Identify strategies for advancing asset management practices and influencing change within state transportation agencies as well as collaborating with agencies to address gaps in their asset management framework, roles and responsibilities, tools and workforce skills.
- Provide input to FHWA, AASHTO and TRB regarding the implementation of state and local TAM plans.

State Practices

This section highlights eight state DOT TAM programs that are employing cross-asset optimization or have plans to do so. We conducted interviews with representatives from six state DOTs—Colorado, New Jersey, North Carolina, Ohio, Texas and Utah—and provide a summary of those discussions as well as related resources. Also highlighted are optimization practices conducted or planned by Florida and Oregon DOTs.

Colorado

Discussion Summary

Contact: Scott Richrath, Performance & Policy Analysis Unit Manager, Division of Transportation Development, Colorado Department of Transportation, (303) 757-9793, scott.richrath@dot.state.co.us.

Background

Colorado DOT is eight months into its yearlong development of the cross-asset optimization element of its asset management program. The resulting system will be a system-level rather than a project-level tool. The new system will bring the analysis conducted in other systems into one platform to examine the impacts of dollars invested and the performance of the investment.

Categories

Five categories of assets are monitored using three systems:

- Pavement (Deighton dTIMS CT, launched in 1998).
- Bridge (Pontis, implemented in 1999).
- Maintenance level of services (SAP Enterprise Resource Planning, implemented in 2006, uses level of service rather than condition or life-cycle analysis).
- Fleet and equipment (SAP Enterprise Resource Planning, since 2006).
- Intelligent transportation systems (ITS) (SAP Enterprise Resource Planning, since 2006).

A buildings module is expected to launch in January 2013 using SAP Enterprise Resource Planning software.

The 120 legacy systems in place prior to Colorado DOT's 2006 migration to SAP were reduced to 50 after the migration.

Tools

Colorado DOT is using Deighton dTIMS CT as its single platform for managing multiple assets. A prior attempt at cross-asset optimization involved the use of Excel and its slider tool, which the agency concluded was not adequate for its needs. Cost to implement the dTIMS tool to analyze the impact of funding for five statewide programs is estimated at \$225,000 with 2,000 hours of staff time devoted to the project.

What's Next

The dTIMS pavement management system has been implemented to consider each asset's condition, location and prioritization with a display of the impact of changes in funding on performance levels. The goal is to bring the other asset categories into dTIMS to allow for visualization of the impact of changing funding levels on all asset categories simultaneously.

Each category has goals for levels of performance, and the current plan for the tool is to identify the impact of funding at a set level for the five primary asset categories (pavement, bridge, maintenance, fleet and equipment, and ITS). At this point, there is no plan to implement project-level optimization across asset categories.

Recommendations for Best Practices

- Determine the business requirements on the front end and obtain consensus from decision makers before selecting technology and establishing a timeline.
- Establish the end goal. For Colorado DOT, this is not project-level analysis. Instead, the agency's goal is to be able to compare funding levels across categories and visually express how changes in funding level for one asset category affect the performance goals for that asset category and the other asset categories under review.

Related Resources

“Cross-Asset Optimization at Colorado Department of Transportation: Developing an Integrated System for Managing Investments in Intelligent Transportation Systems, Fleet, Maintenance, Bridge, and Pavement,” Scott Richrath, Colorado Department of Transportation, *9th National Conference on Transportation Asset Management*, April 16, 2012.

<http://onlinepubs.trb.org/onlinepubs/conferences/2012/assetmgmt/presentations/OtherAssets-Richrath.pdf>

This conference presentation addressed the agency's management of multiple asset categories: pavement, bridges, maintenance levels of service, fleet and ITS. At a programmatic level, the agency's software tool can forecast the impact of investment decisions across multiple asset categories, projecting asset condition at varying asset investment levels.

2011 CDOT Annual Performance Report, Colorado Department of Transportation, 2011.

<http://www.coloradodot.info/library/AnnualReports/FINAL%20FY11%20Annual%20Performance%20Report.pdf/view>

This report outlines the performance measures that are integral to the agency's asset management program. Some examples of objectives for FY 2007-11:

- Percent of bridge deck area in good/fair condition: 94.5 percent.
- Percent of pavement in good/fair condition: 44 percent.
- Overall maintenance levels of service: C+.

Asset Management Implementation Framework for Colorado Department of Transportation, Deighton Associates Limited, August 17, 2010.

See [Appendix A](#).

In 2010, Colorado DOT contracted with Deighton Associates Limited to investigate the use of the Deighton asset management system, dTIMS CT, for strategic planning and cross-asset optimization. Colorado DOT began using dTIMS CT as a decision support tool for its pavement management system in 1998. This report provides a framework for implementing dTIMS CT for strategic planning and analysis in five asset categories: maintenance, pavement, bridge, ITS and fleet. When the analysis is configured for each asset within dTIMS CT, the agency can execute both a tactical analysis for each asset and a strategic analysis where funding for the asset can be assessed against other assets implemented within dTIMS CT to determine how the changing funding levels affect performance objectives over time within each asset category.

Florida

Enhancement of the FDOT's Project Level and Network Level Bridge Management Analysis Tools, Florida Department of Transportation, February 2011.

http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_MNT/FDOT_BDK83_977-01_rpt..pdf

This report evaluates modeling issues that were not possible during previous examinations of Pontis, FDOT's bridge management system. First, researchers performed a sensitivity analysis on the Project Level Analysis Tool (PLAT) and Network Analysis Tool (NAT), and then compared the PLAT and NAT models with *NCHRP Report 590*, which explored the criteria used for priority setting and resource allocation. Key results of this research include enhancements to the PLAT/NAT, including improved deterioration and cost models, and multi-objective optimization.

Related Resource:

Decision Support for Bridge Programming and Budgeting, Florida Department of Transportation, January 2007.

http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_MNT/FDOT_BD543_09_rpt.pdf

In this study researchers developed a bridge decision support tool for network-level analysis of trade-offs between performance and funding using a multi-objective benefit/cost analysis to predict systemwide performance at any given budget or the funding requirement of any target performance level. Researchers developed an optimization model framework using the incremental-benefit algorithm, with performance measures serving as constraints and objectives. Labeled the Network Analysis Tool (NAT), the model was developed as a Microsoft Excel spreadsheet to supplement the functionality of Pontis. The primary purpose of the NAT is to determine the maximum level of inventory performance achievable at any given level of funding over a 10-year planning horizon.

New Jersey

Discussion Summary

Contact: David Kuhn, Assistant Commissioner of Capital Investment, Planning and Grant Administrations, New Jersey Department of Transportation, (609) 530-5228, david.kuhn@dot.state.nj.us.

Background

NJDOT has a clear policy direction—safety and state-of-good-repair investments. The agency launched its Asset Management Steering Committee in 2008 and established performance measures and 10-year targets relatively unconstrained by funding (targets that were deemed desirable yet reasonable given

current funding levels). In addition, the committee developed an overall asset management plan that included a tactical level plan for each class of asset. NJDOT recently reconvened the steering committee.

Mr. Kuhn observes that there are varying levels of asset management: the higher level, which is NJDOT's focus, considers assets at the system level, and a more granular approach attempts to optimize at a project level across systems.

Categories

NJDOT monitors nine asset investment categories:

- Bridge (Pontis).
- Pavement (Deighton).
- Safety.
- Mobility.
- Multimodal.
- Support facilities.
- Mass transit.
- Capital program delivery.
- Aviation.

For each asset category, NJDOT developed background data as well as inventory and condition information. Performance curves identify the 10-year projected performance based on the applicable performance measures and varying funding levels.

Tools

NJDOT does not use a single system to conduct its asset management analysis. The systems used for the various asset categories permit project-level optimization within each asset category with the application of some type of metric appropriate to the asset. The agency has built a data warehouse that pools data and is considering how to apply GIS and other tools to the accumulated data.

What's Next

The next challenges for NJDOT:

- How to use GIS and other tools to select projects that will maximize benefits. The agency conducts some screening today but has an interest in applying a more sophisticated screening process that looks across transportation objectives.
- How to recognize investments in projects that cut across investment categories. Currently, every project is tagged with one of the nine asset categories. Instances where a project addresses multiple objectives should be evaluated in connection with multiple asset categories. Projects that address needs in more than one investment category might be weighted more heavily, or certainly differently, in a cross-asset optimization protocol.

The recommendations included in a 2010 report that describes an asset management decision support system model (see Related Resources below) are on hold for now. The agency is focusing on its needs, seeking input from its Asset Management Steering Committee before moving forward with development of tools or processes that would allow for cross-asset optimization across asset categories. NJDOT has not yet established a timeline for developing this more granular approach to asset management.

Recommendations for Best Practices

- Establish a clear policy direction.
- Bring in stakeholders from across the agency; break down silos.

- Adopt a more data-driven approach to managing assets that generates better questions and improves decision making.
- Consider GIS as a possible answer to optimizing projects across systems.

Related Resources

Asset Management, New Jersey Department of Transportation.

<http://www.state.nj.us/transportation/about/asset/>

NJDOT's asset management web site offers access to policies, goals, performance measures, presentations and publications related to asset management. Asset management was adopted in 2008 as the agency's official approach to managing infrastructure assets and making capital investment decisions.

Asset Management Decision Support System Model, New Jersey Department of Transportation, 2010.

http://www.state.nj.us/transportation/about/asset/pdf/final_dsm.pdf

The result of this research effort is an asset management decision support model that calculates the utility for a user-specified project. The model specifies how NJDOT should use asset management data and systems to support integrated high-level resource allocation decisions and focuses on how to use available data to prioritize candidate projects or project alternatives as well as planned projects. The proposed model, NJDOT Project Planner, evaluates the following investment types: pavement preservation, bridge preservation, major and minor mobility improvements, and safety improvements.

The calculation of a new measure—utility—that underlies the recommended approach provides a quantitative basis for the prioritization process and differs from the most common approach researchers identified in their review. From page 19 of the PDF:

The most common approach implemented for cross-asset allocation is performance targeting, where targets are set for key performance measures and then asset management systems are used to predict performance given a budget scenario.

North Carolina

Discussion Summary

Contacts: Jennifer Brandenburg, State Road Maintenance Engineer, North Carolina Department of Transportation, (919) 733-3725, jbrandenburg@ncdot.gov; Lonnie Watkins, Maintenance Systems Engineer, North Carolina Department of Transportation, (919) 212-6092, lwatkins@ncdot.gov.

Background

Asset management is being conducted for maintenance management and pavements. A bridge asset management system has been implemented but has not been made available at the division level.

Categories

NCDOT is monitoring three asset investment categories using AgileAssets software:

- Maintenance management.
- Pavement (implemented two years ago).
- Bridge (recently implemented; not yet available at the division level).

A Mobility Analyst module is in development by another NCDOT unit. Eventually, the mobility module will be rolled into a single system with the three other asset categories.

While the individual systems are capable of scenarios analysis—optimizing within the asset category—NCDOT will not employ full optimization across asset categories at the system and project levels until the maintenance, pavement and bridge modules are fully deployed at the end of this year.

Tools

NCDOT uses AgileAssets software for three asset categories (maintenance, pavement and bridge) and will be using the AgileAssets' cross-asset optimization tool beginning next year. Prior to 2003, the agency used in-house systems that served primarily as planning tools. In 2003, NCDOT contracted with AgileAssets to migrate its maintenance management asset management system from an NCDOT mainframe to a vendor-supplied program. Two years ago, the agency's in-house pavement management system was migrated to an AgileAssets system.

What's Next

NCDOT is at the forefront of the application of full cross-asset optimization among state DOTs, expecting to begin working with its AgileAssets cross-asset optimization tool to optimize within and across asset categories at both the system and project levels beginning in January 2013. Features of the cross-asset optimization tool include the ability to review project schedules and recommend coordination of related projects in a single year to limit costs.

NCDOT will meet soon with representatives from New York State DOT to demonstrate and discuss the AgileAsset tools used for the NCDOT's three asset categories (maintenance, pavement and bridge). New York State DOT is contemplating development of a TAM capable of cross-asset optimization, beginning its development with a cross-asset optimization tool and working down the hierarchy. New York State DOT's individual assets are managed with different vendor systems, and development of the cross-asset optimization tool might be one way to integrate the disparate systems. New York State DOT contacts:

- Brad Allen, Maintenance Program Planning Division, New York State Department of Transportation, (518) 457-6435, ballen@dot.state.ny.us.
- Steve Wilcox, Associate Director of Maintenance, New York State Department of Transportation, (518) 457-6435, swilcox@gw.dot.state.ny.us.

Recommendations for Best Practices

- Avoid “putting the cart before the horse.” Get all system modules in place before attempting to deploy cross-asset optimization.
- Recognize that cross-asset optimization is a culture change requiring staff to pull back to see the big picture.
- Understand that at times budgets may be constrained to a particular system (for example, an agency may focus on bridge projects and limit funding to other asset categories) or to a particular region within a state, placing “strings” on funding that limit the effectiveness of a cross-asset optimization tool.
- Obtain the trust and support of decision makers at the state and agency levels.
- Plan for change management in the optimization system.

Related Resources

“**Active Asset Management in State DOTs**,” Stuart Hudson, Charles Pilson, Eric Perrone, AgileAssets Inc., *9th National Conference on Transportation Asset Management*, April 2012.

<http://onlinepubs.trb.org/onlinepubs/conferences/2012/assetmgmt/presentations/Forecasting-Hudson-Pilson-Perrone.pdf>

NCDOT's current integrated asset management process includes pavement, bridge and maintenance, with plans for mobility and safety. Each area contributes multiple optimized budget plans to cover a range of

possible funding scenarios for each category. The goal for the Mobility Analyst module is the optimization of mobility through an evaluation of congestion mitigation strategies that include road widening, managed lanes, traffic incident management, traveler information services and road weather management. Work plans are based on an optimization analysis.

“Using Integrated Asset Management System to Perform Corridor-Level Analysis for Planning and Scheduling Bridge and Pavement Projects,” Abhishek Bhargava, Pascal Laumet, AgileAssets Inc., *9th National Conference on Transportation Asset Management*, April 17, 2012.

<http://onlinepubs.trb.org/onlinepubs/conferences/2012/assetmgmt/presentations/Tradeoffs-Bhargava-Laumet.pdf>

This conference presentation described NCDOT’s asset management system using the example of an I-40 corridor analysis. Objectives for the analysis:

- Identify optimal pavement and bridge projects over a 25-year period that maximizes bridge and pavement condition and meets budget constraints.
- Prepare an implementation schedule and re-evaluate the five-year plan. Do bridge and pavement projects together where possible, and estimate traffic control and mobilization cost savings.

Steps in the process were:

- **Step 1:** Define network and identify pavements and bridges in network.
- **Step 2:** Run a range of candidate scenarios in the bridge and pavement management systems.
- **Step 3:** Analyze scenario combinations.
- **Step 4:** Identify preferred system optimal solution.
- **Step 5:** Prepare implementation work plan and re-evaluate optimality.

“Statewide Implementation of a Maintenance Management System in North Carolina,” Charles C. Pilson, Lacy Love, Jennifer P. Brandenburg, *Transportation Research E-Circular*, No. E-C098, July 2006: 117-134.

<http://onlinepubs.trb.org/onlinepubs/circulars/ec098.pdf>

The paper primarily describes the implementation of NCDOT’s maintenance management system and basic operation of the new system, but also offers insights and hindsight based on experiences since the system went live.

Ohio

Discussion Summary

Contact: Andrew Williams, Administrator, Office of Technical Services, Division of Planning, Ohio Department of Transportation, (614) 752-4059, andrew.williams@dot.state.oh.us.

Background

Ohio DOT is implementing pavement asset management—pavement is the state’s largest asset—in an open architecture system that allows for incorporation of other assets. Optimization is now limited to the pavement system at the system level, not at the individual asset level. Ohio DOT has opted to focus less on the collection of condition data and more on the location and age of its assets. For example, the agency gathers data on the age and location of signs and barrier systems and determines a systematic replacement schedule based on the age of each asset. For assets such as barriers, the timing of replacement may also be affected by safety considerations.

Categories

Ohio DOT plans to include three asset categories in its TAM:

- Pavement (launched in 2011).
- Bridge.
- Culvert.

Other factors such as signs, barriers and lighting will be considered but not at the level of making or not making an investment. The focus of the system is on network optimization rather than optimization across asset categories.

Tools

Ohio DOT uses Deighton dTIMS for its pavement management system. The system uses Markov performance prediction analysis to generate forecasts and develop work plans with a goal of achieving a steady-state system condition.

A prototype system is in development that will allow for cross-asset optimization at the system level for the agency's three major asset categories: pavement, bridge and culvert. The prototype will be incorporated into the agency's Web-GIS (see Related Resources below), with a final report on the prototype project expected in the spring of 2013.

What's Next

The prototype in development is expected to provide the same type of functionality associated with the pavement system across multiple assets. Ohio DOT expects to use the prototype system in development as the basis for issuing a request for proposal (RFP) to vendors for the development or modification of an off-the-shelf tool to meet the agency's requirements.

Recommendations for Best Practices

- Databases are key to a successful system.
- Data is the most significant element of the system, but it is also the most expensive and most complicated system component.
- Take small steps forward; better results come from a patient approach.

Related Resources

“Pavement Asset Management Decision Support Tools: Ohio Department of Transportation Case Study,” Eddie Chou, Andrew Williams, *9th National Conference on Transportation Asset Management*, April 2012.

<http://onlinepubs.trb.org/onlinepubs/conferences/2012/assetmgmt/presentations/Data-A-Chou-Williams.pdf>

This conference presentation described Ohio DOT's next steps for TAM:

- Implementing a commercial pavement management system (Deighton).
- Developing an integrated asset management system prototype through the University of Toledo.
- Implementing Web-GIS application for displaying, distributing and analyzing pavement and other assets.
- Developing the framework for a consolidated asset management database.

“A Look at the Ohio Department of Transportation’s (ODOT) Asset Management Geospatial Tools,” *GIS in Transportation*, Federal Highway Administration, Spring 2012.

http://www.gis.fhwa.dot.gov/documents/Newsletter_Spring2012.htm

This article describes the next steps for Ohio DOT in developing its cross-asset optimization prototype:

ODOT is currently developing a consolidated database with an asset management framework that will have an information technology protocol for all asset data to be brought into the database. This framework will identify the business/asset owner, a set of standards for collecting the data, and specified data formats.

Oregon

Discussion Summary

Contact: Laura Hansen, Asset Management Integration Coordinator, Oregon Department of Transportation, (503) 986-3308, laura.l.hansen@odot.state.or.us.

Ms. Hansen reported that limited resources and her department’s current workload preclude her assistance with this report until winter 2012 and recommended a review of Oregon DOT’s updated Asset Management Strategic Plan (see Related Resources below).

Related Resources

Asset Management Strategic Plan, Oregon Department of Transportation, November 2011.

http://www.oregon.gov/ODOT/TD/asset_mgmt/docs/plans/04-amsp-10-111711_final.pdf

The plan’s four goals:

- Foster integrated strategic decision making.
- Sustain and establish a complete and reliable asset inventory.
- Build a fully integrated data system or collection of systems.
- Create integrated reporting and analysis tools that make use of the integrated data system.

Transportation Asset Management: The Oregon Department of Transportation’s Roadmap for Maximizing Assets, Oregon Department of Transportation, undated.

http://www.oregon.gov/ODOT/TD/asset_mgmt/docs/Documentation/AM_Brochure_REV_SS_2.pdf?ga=t

This brochure summarizing Oregon DOT’s approach to TAM includes the key elements of the agency’s asset management program:

- Setting strategic goals for the program.
- Determining standards for data collection and storage.
- Keeping a reliable, accurate inventory of assets.
- Providing robust asset reporting and analysis, including cross-asset analysis.
- Focusing on customer service.
- Making asset management “system oriented,” so that all its pieces are connected.

“Progress Report on Oregon’s Efforts to Integrate Its State Transportation Improvement Program Project-Selection Process with Pontis,” Dawn Mach, Bert Hartman, *Transportation Research E-Circular*, No. E-C128, October 2008:16-28.

<http://onlinepubs.trb.org/onlinepubs/circulars/ec128.pdf>

Beginning in 2006, ODOT resumed efforts to implement Pontis. This report outlines practical aspects of progress and challenges in implementing Pontis while attempting to maintain the comprehensive nature of the 12-category bridge management system in the Statewide Transportation Improvement Program development process and implement a corridor-based approach to project selection. The authors discuss the apparent difficulty in implementing Pontis simultaneously for cross-asset management resource allocation and project-level decision making.

Texas

Discussion Summary

Contact: Ron Hagquist, Operational Excellence Office, Texas Department of Transportation, (512) 936-9512, ron.hagquist@txdot.gov.

Background

TxDOT has undertaken an allocation formula advisory project that will consider a system for allocating scarce transportation funds using six criteria:

- Optimization: How to get the most bang for the buck.
- Decision analysis: How to address multiple relevant factors.
- Macroeconomics: Does the allocation make economic sense?
- Econometrics: Are the formulas correct?
- Fair division: Money is short; is it allocated fairly?
- Market analysis: Make sure you understand customer values.

Categories

TxDOT is focusing on two categories of assets: pavement and bridges.

Tools

TxDOT will soon commit to the purchase of a commercial pavement management system and is beginning consideration of a separate bridge management system. To date, there has been relatively little focus on cross-asset optimization. While the pavement and bridge asset management systems will be separate, the systems will be capable of communicating across platforms and allow for cross-asset optimization at the system level. The bridge management system is expected to optimize at the project level within the asset category but not across asset categories.

What’s Next

- A model will be developed that addresses capacity versus maintenance.
- A pilot project to gather customer input and reflect it appropriately in allocation formulas is expected to begin in fall 2012.

Related Resources

“Use of Management Science Analytics for Asset Management at TxDOT,” Ron Hagquist, Texas Department of Transportation, *9th National Conference on Asset Management*, April 17, 2012.

<http://onlinepubs.trb.org/onlinepubs/conferences/2012/assetmgmt/presentations/Tradeoffs-Hagquist.pdf>.

This conference presentation described a number of activities at TxDOT related in some way to optimization, including:

- Maintenance section location optimization: Identifies the least-cost number and location of maintenance sections.
- Advance right of way optimization tool: Identifies parcels most likely to escalate in price to identify cost-effective purchases.
- Fleet replacement optimization: Identifies least-cost vehicle replacement policies by vehicle type and under budget constraint.
- Pavement preservation optimization: Identifies the most beneficial condition goals within budget and optimizes maintenance scheduling.
- Project evaluation tool: Selects the best mobility option using multiple criteria.

Asset Management Literature Review and Potential Applications of Simulation, Optimization, and Decision Analysis Techniques for Right-of-Way and Transportation Planning and Programming,

Texas Department of Transportation, Report No. FHWA/TX-07/0-5534-1, April 2007.

<http://tti.tamu.edu/documents/0-5534-1.pdf>

This report documents the work performed during Phase I of Project 0-5534, “Asset Management—Texas Style.” The specific research focus area was resource allocation decisions regarding advance acquisition of right of way and the construction of new highway capacity facilities. Simulation, optimization and decision analysis methodologies were explored for examining the trade-offs between using funds for these two alternative purposes.

Utah

Discussion Summary

Contact: Stan Burns, Director of Asset Management, Utah Department of Transportation, (801) 965-4150, sburns@utah.gov.

Background

Utah DOT’s experience with asset management dates back to the 1970s, beginning with pavements. Recently bridges were added to the agency’s asset management system.

Cross-asset optimization at the project level is in process for pavements, bridges and safety. Utah DOT is conducting system-level cross-asset optimization for these asset categories. Silos for pavement and bridges are considered in tandem, with the optimization models calculating and displaying the effects of movement of dollars from one system to another, but not to specific bridge or pavement projects. Ultimately, Mr. Burns envisions that the Utah DOT system will be capable of determining if a capacity project that reduces time delays and accidents has a greater cost/benefit than extending the life of a particular bridge.

Utah DOT applies a four-step process to optimizing assets:

- Know where the assets are and how many there are.
- Know the condition of the assets.

- Create deterioration curves that identify how quickly the asset will deteriorate given a specific level of funding over time. These curves will adjust as funding is shifted among asset categories to identify how performance of the asset will be affected by increases or decreases in funding.
- Identify how to extend the life of the asset using a cost/benefit analysis to identify a maintenance strategy.

Categories

When fully implemented, Utah DOT's TAM will allow for cross-asset optimization of the following asset categories:

- Pavement (beta testing completed 10 years ago).
- Bridge (beta testing in process; expect to complete by the end of this year).
- Safety.
- Signs.
- Mobility.

Tools

Deighton's dTIMS software is used to manage investments in pavements, bridges and safety. Other asset categories will be added to the tool over time.

- dTIMS software is used as the agency's pavement management system.
- Pontis is used to capture bridge inventory data.

The Safety Management System is an in-house database application used by Utah DOT for the entry, storage, retrieval and analysis of crashes in the state.

The agency solicited vendor solutions that could gather and integrate data for all assets owned by Utah DOT, with the exception of culverts, and provide a photolog. The system also had to be capable of querying, sorting and reporting on all assets in the system. Mandli Communications Inc. was selected through the RFP process. Its Roadview Workstation 1.0.4 is now in beta testing.

The vendor is collecting data at highway speeds for all assets except culverts. Using photorecognition, downward cameras and point clouds (lasers that send out lights that bounce off objects; every point coming back to a receiver is geolocated), assets can be located and the condition identified quickly and efficiently.

What's Next

Developments in process for Utah DOT's TAM program are expected to unfold over the next five years:

- Years 1 through 3: Signs.
- Year 4: Mobility.
- Year 5: A comprehensive TAM system that allows for cross-asset optimization within and across all asset categories at the system and project levels.

Recommendations for Best Practices

- Start small and grow from there. Mr. Burns contrasts this approach with that of Oregon DOT, which he notes has elected to work with all asset categories at once.
- Conduct a gap analysis to identify if the agency has the data it needs to conduct a robust analysis.
- Recognize that setting the value, or weighting, for a project is the most difficult challenge.

Related Resources

Asset Management Manual of Instruction, Utah Department of Transportation, undated.

<http://www.udot.utah.gov/main/uconowner.gf?n=2949032180860286>

This manual outlines a timeline for collection of data, the details of data collection, when the data is added to the asset management system and how the data is manipulated in the agency's asset management system for pavements, structures and safety. In general, asset data collection is categorized by location, physical attribute and condition. Data is manipulated using Deighton's dTIMS software.

Cross Asset Prioritization, Utah Department of Transportation, undated.

<http://www.udot.utah.gov/main/uconowner.gf?n=2949122268866911>

Utah DOT developed this matrix of scores to make cross-asset prioritization decisions between structures and pavements. Utah DOT's Safety Index is reflected in the benefit weighting of pavements to better equate structures with pavements within the asset model.

"Asset Management for Tough Economic Times: Cross Asset Analysis and Optimization," Richard Fox-Ivey, Deighton Associates Limited, *Pavement Evaluation 2010*, October 2010.

<http://www.cpe.vt.edu/pavementevaluation/presentations/Fox-Ivey.pdf>

"Utah DOT Asset Management Case Study" begins on slide 33 of this presentation, which addressed data flow and analysis and described how safety factor weighting is used for cross-asset analysis and optimization in pavement project selection. An example shows how safety is used to decide among three sections of pavement with identical repair costs.

"Integrating Pavement Management into a Comprehensive Strategic Asset Management System for the State of Utah Department of Transportation," Jeffrey L. Zavitski, R. Tim Rose, Gary Kuhl, *7th International Conference on Managing Pavement Assets*, 2008.

<http://www.udot.utah.gov/main/uconowner.gf?n=270018528301402275>

This conference paper addressed the technical and institutional aspects of the integration of Utah DOT's pavement management system into the agency's asset management system (AMS). See page 10 of the PDF for Figure 6, "Cross Asset Analysis and Optimization" Analysis Framework. Also from page 10:

When the strategies have been generated, the AMS allows for the optimization of those strategies to produce investment scenarios for each asset individually or across asset groups. The AMS then can produce reports and graphs to illustrate the differences in asset condition and any other performance measures (impacts on the economy, society, and the environment) for each investment strategy and each asset. UDOT can determine the immediate effects of transferring investment dollars from preservation to rehabilitation, one asset to another and any combination.

Related Research

Domestic

"System Tiers: Making Tough Choices for Asset Management," Stan Burns, Stephanie Weigel, Scott Zainhofsky, Chip Getchell, Anne Emidy, Jeffrey Zavitski, *Eighth International Conference on Managing Pavement Assets*, 2011.

Citation at <http://trid.trb.org/view/2011/C/1136332>

This conference paper examined efforts by state DOTs in setting performance goals and budgets based on system tiers and the impacts of those tiers on pavement and asset management systems. The authors include a discussion of management systems employed by Utah, North Dakota and Maine DOTs along with an examination of the impacts of the system tiers.

“A Flexible Framework for Sustainable Multi-Objective Cross-Asset Infrastructure Management,” Mohammadsaied Dehghanisani, Gerardo W. Flintsch, Alejandra Medina Flintsch, *TRB 89th Annual Meeting Compendium of Papers DVD*, Paper #10-3249, 2010.

Citation at <http://trid.trb.org/view/2010/C/910969>

This conference paper reviewed the literature and current practice in cross-asset management. The research confirms the promising potential for developing a comprehensive framework for sustainable multi-objective cross-asset management.

Uncertainty-Based Tradeoff Analysis Methodology for Integrated Transportation Investment Decision-Making, Purdue University, Federal Highway Administration, NEXTRANS Project No. 020PY01, October 28, 2009.

<http://www.purdue.edu/discoverypark/nextrans/assets/pdfs/completedprojects/Final%20Report%20020.pdf>

This study addressed the need for a multi-objective decision-making tool that integrates a transportation agency’s various management systems, incorporates uncertainty and helps decision makers assess the trade-offs between the systems’ performance measures. A key product of this study is the development of a novel project selection framework formulated as a multi-objective optimization problem.

International

“Cross-Assets Trade-off Analysis: Why Are We Still Talking About It?” Donath M. Mrawira, Luis E. Amador, *TRB 88th Annual Meeting Compendium of Papers DVD*, Paper #09-1896, 2009.

Citation at <http://trid.trb.org/view/2009/C/881421>

From the abstract: This paper presents a cross-asset optimization and demonstrates its application to the strategic, very long-term (20+ years) planning for mixed assets. The case study is based on actual and complete dataset of four types of transportation assets of the province of New Brunswick, Canada. The optimization and trade-off analysis for this paper was carried using a tool called TAMWORTH. The cross-asset trade-off approach in TAMWORTH is based on linear programming and innovative improvements that reduces the problem size, and facilitates rapid solution of the multi-period optimization problem. With these innovations, TAMWORTH is capable of applying global optimization to conduct cross-asset trade-off analysis for over 25 years for the full set of transportation assets.

Application of the Analytic Hierarchy Process in Road Asset Management: User Manual, AUSTRROADS, May 2007.

Publisher’s information available at <https://www.onlinepublications.austrroads.com.au/items/AP-T84-07>

This manual provides guidance for the application of the analytic hierarchy process (AHP) as a decision support tool in road asset management. AHP is a multi-criteria analysis technique that allows trade-off between objectives with different measurement units. With AHP, the user can rank or prioritize a number of options according to their performance in achieving the objectives or assessment criteria. In this manual, the steps involved in applying AHP are demonstrated by examples, including ranking maintenance intervention criteria and allocating funding across asset categories, and trading off maintenance intervention criteria across assets to meet budget limits.

Research in Progress

NCHRP projects in process are developing performance objectives and measures of effectiveness for use in optimizing resource allocation across asset categories and considering the current state of the practice of TAM in state DOTs. A TxDOT project is investigating the use of fair division algorithms as a mechanism for allocating funds and resources among competing interests.

Resource Allocation Framework to Meet Highway Asset Preservation Needs, NCHRP Project 14-21, expected completion date: July 19, 2012.

<http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2718>

In this project, researchers will develop common performance objectives and measures of effectiveness that may be used to optimize resource allocation for preservation of assets across the entire range of highway assets for which a state DOT is responsible.

This project is expected to include:

- Preparation of an annotated literature review on optimization criteria and objectives to allocate resources across various transportation asset categories.
- Identification of optimization objectives and criteria that may be suitable to allocate preservation resources across a broad portfolio of highway asset categories.
- Assessment of the potential advantages and disadvantages of the optimization objectives and criteria for use in the intended context.
- Assessment of potential issues associated with implementing the most advantageous optimization objectives and criteria in a practical optimization model within state DOTs.
- Demonstration and documentation of the use of the recommended optimization objectives and criteria in the allocation of resources across highway asset categories through realistic case study examples.
- Identification of specific future research needed to achieve the implementation of allocation optimization models for the preservation of a broad portfolio of highway asset categories within state DOTs.

“Use of Transportation Asset Management Principles in State Highway Agencies (Topic 43-01),”

Federal Highway Administration, National Cooperative Highway Research Program, American Association of State Highway and Transportation Officials, expected completion date not indicated.

<http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=3211>

AASHTO’s recent publication of Volume 2 of the Asset Management Guide: A Focus on Implementation provides a systematic process to help agencies align investment decisions with strategic goals. With many of the examples included in the guide from outside the United States, the degree to which TAM principles are being used by state DOTs and the advancements that have taken place since the 2007 publication of FHWA’s U.S. Domestic Scan Report are not well understood. Among the topics the synthesis will examine and summarize are changes that have been made, or are planned, to apply TAM practices within and across all asset classes.

“Using ‘Fair Division’ Methods for Allocating Transportation Funds,” Texas Department of Transportation, Project No. 0-6727, expected completion date: August 31, 2013.

http://ftp.dot.state.tx.us/pub/txdot-info/rti/research_program_2012.pdf

See page 135 of the PDF for the project objective:

The objective of this project is to investigate fair division algorithms and methods for the allocation of transportation funds and/or resources among competing interests at TxDOT. The project involves identifying critical tier allocation areas and formulating an overall comprehensive model to enhance current allocation decision making processes. Enhanced allocation methods should lead to envy-free, efficient, and equitable distribution of funds and resources.

Related Resource:

“Using ‘Fair Division’ Methods for Allocating Transportation Funds,” Carlos M. Chang-Albitres, Edith Montes, *9th National Conference on Transportation Asset Management*, April 16, 2012.

<http://onlinepubs.trb.org/onlinepubs/conferences/2012/assetmgmt/presentations/Tradeoffs-Chang-Albitres-Montes.pdf>

This conference presentation began with a discussion of project objectives:

- To investigate fair division algorithms and methods for the allocation of transportation funds and/or resources among competing interests at TxDOT.
- To formulate a comprehensive model to enhance the current allocation decision-making processes based on fair division concepts.

This research appears to be focused on fair division methods to allocate funds to roadway projects and not among competing systems.

Vendors

This section provides links to vendor web sites describing the software and services used in some of the state DOT TAM programs highlighted in this report.

AgileAssets Inc.

<http://www.agileassets.com/>

Specializing in asset management for government agencies, AgileAssets’ suite of software tools focuses on maximizing asset condition, maintenance dollars and long-term life cycle. Among the state DOTs queried for this report, North Carolina DOT is using AgileAssets software. NCDOT reports that New York State DOT also uses AgileAssets software.

Related resource:

“NCDOT Creates a Cohesive Culture with AgileAssets Inc.,” AgileAssets Inc., undated.

http://www.agileassets.com/ncdot_chooses_agileassets/

This success story from the AgileAssets web site describes NCDOT as “one of the first states with a comprehensive and fully integrated asset management system.”

Deighton Associates Limited

<http://www.deighton.com/dtims.html>

Deighton’s dTIMS (Deighton’s Total Infrastructure Management System) software aids transportation agencies in making decisions concerning the life cycle of assets such as roads, bridges, water and safety. Among the state DOTs queried for this report, Colorado, New Jersey, Ohio and Utah DOTs are using the dTIMS software.

Mandli Communications Inc.

<http://www.mandli.com/>

From the web site: Roadview Workstation is an interactive software environment for working with photolog images and data collected with Mandli's systems. The software seamlessly integrates high-resolution right-of-way and downward images, GPS data, centerline maps, orthophotos, asset data, and existing database data into an intuitive point-and-click interface. A complete inventory can be taken of any asset viewable in consecutive photolog images.

Utah DOT is using the Roadview software.

SAP

<http://www.sap.com/solutions/business-suite/erp/index.epx>

Colorado DOT is using SAP's Enterprise Resource Planning software to manage several of its asset categories.

**Asset Management
Implementation Framework for
Colorado Department of Transportation
By Deighton Associates Limited**

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1. Introduction

Declining tax revenues, increasing construction and maintenance costs coupled with aging infrastructures and increasing user demands have greatly increased the need for effective asset management by transportation agencies throughout the world. New performance measures and the ability to investigate transferring funds from one program area to another to trade-off different levels of service against limited resources, have been recognized as key needs for managing transportation networks going forward in this tough economic climate.

Colorado Department of Transportation (CDOT) has recognized the need to make "tough choices" regarding the financing of transportation projects throughout Colorado. The **2035 Statewide Transportation Plan**¹ (March 2008) clearly outlines that declining revenues will lead to reduced funding in some program areas so that funding can be applied on the most critical transportation system program needs.

The Statewide Plan provides several responses to the funding shortfall including the following:

"Improved tools will be developed to aid the Transportation Commission in analyzing and making the best tradeoffs when establishing funding priorities. These could include establishing and focusing investments primarily on priority roadways using possible criteria such as roadway

¹ 2035 Statewide Transportation Plan, "Moving Colorado: Vision for the Future", March 20, 2008, Colorado Department of Transportation, Statewide Planning Group

usage, truck traffic, system connectivity, and / or lifeline routes to communities."

In order to help demonstrate the effects of increasing or decreasing funding changes on different program areas, CDOT requires strategic level asset management analysis tools to supplement existing tactical asset management tools implemented within CDOT.

In 2010 CDOT contracted with Deighton Associates Limited (Deighton) to investigate the use of the Deighton asset management system (dTIMS CT) for strategic planning and cross asset trade-offs within CDOT. CDOT has been a Deighton client since 1997 and uses dTIMS CT as a decision support tool for the CDOT Pavement Management System (PMS).

Recognizing that the CDOT PMS, implemented within dTIMS CT, could also be used for strategic planning and cross asset trade-offs, CDOT sought to determine how dTIMS CT could be implemented within the Planning Division for strategic planning and economic trade-offs and which assets might be included. By undertaking a framework development study Deighton and CDOT would investigate the current management systems implemented within the agency and determine the following:

- Data Flows;
- Data Management Support Requirements
- I.T. Support Requirements;
- Staff Support Requirements;
- Consultant Support Requirements; and

- Analysis Outcomes.

During the week of June 7th to June 11th, 2010, Deighton travelled to CDOT to meet with the various asset managers to discuss the current management philosophy and methodology as well, as the current management systems used within the asset group to manage the assets under their jurisdiction.

This report "CDOT Asset Management Implementation Framework" provides a summary of the meetings held that week and provides a framework for implementing dTIMS CT for Strategic Planning and Analysis.

The remainder of this section will introduce Deighton and the dTIMS CT Asset Management System.

Chapter 2 will discuss the implementation of dTIMS CT for Strategic Asset Management within an Agency and provide the conceptual and technical details of the implementation. Following that, the report will investigate each of the asset groups (Maintenance, Pavement, Bridge, ITS, Fleet) and then provide proposed analysis methodologies and estimates of resources to implement the assets within the strategic asset management analysis for CDOT.

1.1 Deighton Associates Limited (Deighton)

Deighton has been in business for over 25 years and today is a leader in Transportation Infrastructure Asset Management.² Over the past two decades, Deighton has evolved from a small engineering firm producing client specific applications for pavement management, into a world class software

² Deighton provides asset management services, based on dTIMS CT, to 19 US state DOT's and over 400 agencies around the world.

development organization continually developing and supporting one of the most recognized Commercial Off-The-Shelf (COTS) Asset Management Solutions available today, Deighton's Total Infrastructure Management System, more commonly known as: dTIMS CT.

From humble beginnings as a simple data warehouse of road network information, dTIMS CT progressed into a full featured decision support tool providing performance modeling capabilities that can deliver current strategic details, historical information and future projections on infrastructure condition for an agency's entire transportation infrastructure network based on arrays of definable budget scenarios. This powerful application developed into an essential planning tool for asset managers in charge of transportation networks of any size, from small towns to entire countries.

Our clients want to know the answers to:

- What is the current condition of my network?
- How much is it going to cost me to maintain the condition of my network over a five, ten, fifteen or twenty year planning horizon?
- What type of construction / maintenance program is necessary to maintain or improve the condition of my network?
- What will my network look like in ten years based on projected budget scenarios?

dTIMS can answer these questions and many more regarding your transportation infrastructure.

As dTIMS CT matured over its 23 year history, Deighton began expanding its expertise beyond just pavements. Our clients wanted to apply the advanced analysis capabilities within dTIMS CT to their other assets, such as roadside assets, bridges and sub-surface utilities. Deighton then developed partnerships with companies with expertise in bridge condition assessment and subsurface utility management. By leveraging the expertise gained through these strategic partnerships, Deighton is now able to deliver software tools and valuable expertise in not only pavements, but also bridges, subsurface utilities, roadside assets, etc. Our most progressive clients are using dTIMS CT to manage not only pavement and bridges, but also safety and traffic data and then incorporate it into the entire network analysis by using the advanced cross-asset analysis capabilities within dTIMS CT.

Today, dTIMS CT is in use around the world to manage many different types of assets. There are over 400 agencies worldwide that are using dTIMS CT, including 19 of the state Departments of Transportation (DOTs) in the United States of America.

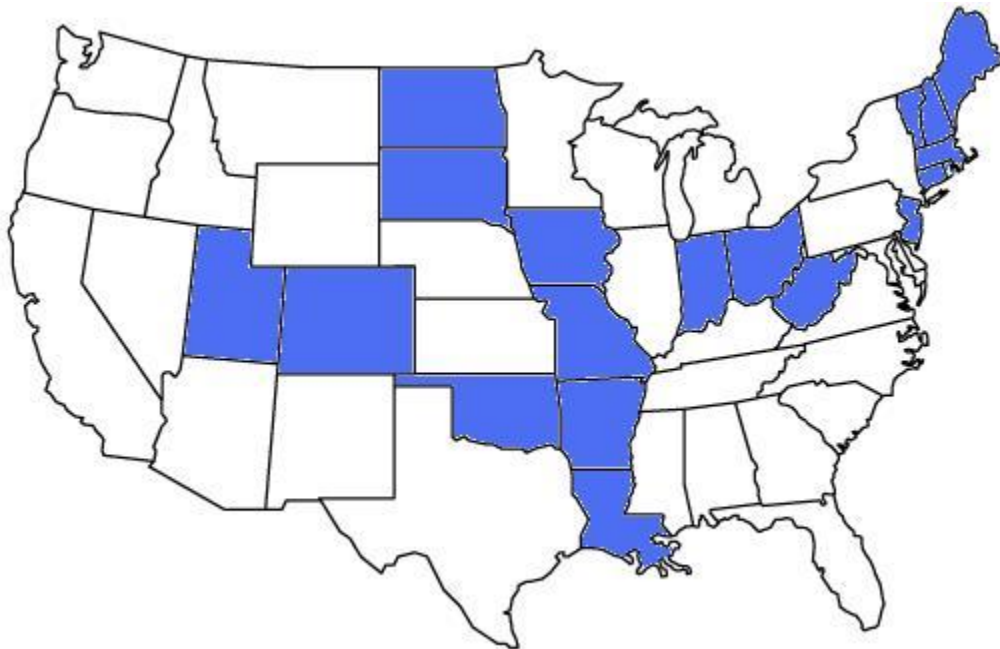


Figure 1: United States State Level dTIMS CT Implementations

Each state level user of dTIMS CT has an implementation which provides an enterprise solution to manage their pavement assets. Many of the state level dTIMS CT users manage additional assets, including bridges and culverts.

Deighton offers tremendous sustainability to its clients as indicated by the longevity of their business relationship. Eleven active state DOTs have reached, or are within, three years of celebrating 20 years of customer support and continued software maintenance with Deighton. Our commitment to our clients is unparalleled.

The recent shift towards multiple asset management, cross asset co-ordination and optimization has given our clients the added benefit of pursuing the management of those assets using the same proven and familiar software platform that they have implemented at the tactical and operational level for pavement management. The benefits have come in the form of financial and time savings that were realized by being able to remain with the same software platform for multiple asset management and avoiding the inherent risks associated with introducing new software into the management process.

Expanding into a multiple asset management system for an agency using dTIMS CT is a relatively simple process. Deighton has designed dTIMS CT from the ground-up to be a user-accessible, open framework platform, not a modular platform as is typical for other software vendors. A modular structure would require the purchase of additional modules to expand the functionality of the software, whereas an open framework platform, specifically dTIMS CT, provides the user with the ultimate freedom to expand to a limitless number of assets, each having a limitless number of attributes.

Deighton's Total Infrastructure Management System (dTIMS CT) combines network data storage, external application integration, powerful analysis tools such as dynamic segmentation and Concurrent Transformation™ as well as comprehensive reporting tools to provide transportation asset managers with an indispensable decision support and planning tool for their road networks.

1.2 dTIMS CT

dTIMS CT, is the core application in Deighton's asset management offering. It is a sophisticated engineering tool designed to provide an asset inventory of multiple asset types, related to one another using a Linear Referencing System (LRS). It is designed to achieve maximum efficiency when dealing with linear transportation infrastructure networks such as roadway or bridge assets. In addition to the asset inventory, dTIMS CT offers sophisticated deterioration modeling tools; which, when coupled with the planning and budgeting tools, makes for an extremely powerful capital investment and maintenance planning tools for all transportation related assets in an agency. Over the past 25 years, dTIMS CT has become the industry leader in transportation infrastructure management software.

dTIMS CT combines the convenience and cost advantage of COTS software with the potential for any agency to make it as "custom" as it wishes by incorporating its very own database structure and analysis parameters that have been refined over time. dTIMS CT will be configured during implementation to provide agency staff with the pavement management and data integration tools they require. The flexibility of dTIMS CT leaves the door open for future modifications to the database structure or expansion of the initial analysis methodology to include future data availability.

Where dTIMS CT stands out from the competition is that it allows users to customize their Asset Management System themselves, without having to pay for additional programming for existing product modifications. In fact, all implementations of dTIMS CT are built on a single source code. Therefore, all dTIMS CT users, whether they are located in Utah, Louisiana or New Zealand, are using the same software, built on the unique code. This approach, adopted by Deighton in its early days, ensures a robust universal product, reduces the risks of errors and helps to mitigate development costs. These benefits translate into lower technical and financial risks for users.

Please note that dTIMS CT is not a Management Suite comprised of a number of modules that need to be purchased, implemented, maintained and supported separately. dTIMS CT is an open architecture framework that provides users with the flexibility to creatively model the type of asset they wish to manage, using the management philosophy that they wish to employ and the analysis parameters that are specific to their assets. The benefit that this will give to an agency is twofold:

- During implementation there is no data transformation required to accommodate external data
- Once implementation is complete the database structure and analysis models are available in their entirety for review, modification and expansion

It is important to note that the open architecture design of dTIMS CT makes it easy for an agency to expand the Asset Management System (AMS) to other transportation related assets at any time without the added expenditure of supplementary software modules, support and maintenance. Additional assets, models, management philosophies and analysis parameters may be configured at any time into dTIMS CT. dTIMS CT goes beyond offering users the mere

ability to store data related to other assets within their AMS. A user can choose to store other asset data in dTIMS CT independent of its final use. Initially, it can be used simply for query and reporting purposes, then as an enhancement to the AMS and finally as the basis for a complete management system for that asset. All within the same software application, dTIMS CT, with “right click” simplicity. As the AMS matures, asset managers will be able to concurrently manage assets such as roads, bridges, structures, culverts, traffic, safety and other roadside appurtenances using a single application and even optimize budgets across those same assets.

dTIMS CT KEY FEATURES

- **Manage Multiple Assets**

Manage all assets including, but not limited to: roads, bridges, signs and sub-surface utilities in a single application.

- **Decision Support Tool**

Predict future conditions for every asset and show how each will perform under existing conditions.

- **Work Program**

Provide multi-year project analysis for establishing priorities for work programs.

- **Optimization**

Multi objective optimization using feasible solutions for each element constrained by user defined budgets, resources or restrictions (maximize benefits, minimize agency cost, reduce public costs and delays, maximize performance measures) as defined by your organization.

- **Preventative Maintenance**

Predict the best time to perform preventative maintenance and the estimated cost to keep assets in good order.

- **Strategies**

Show multiple engineering strategies for each project, including doing nothing, and quantify the impact of delaying or moving forward the timing of a treatment.

- **Agency Goals**

Determine affordable future levels of service or set performance goals for performance based budgeting.

- **Budgeting**

Show the effect of individual project budget goals for individual work divisions, managers and districts based on network-wide goals and needs for multiple assets.

2. Proposed Implementation Framework

2.1 Asset Management Philosophy

Much has been written about asset management and many different definitions of asset management have been published by transportation agencies around the world. There is no shortage of information regarding asset management best practice and many handbooks / guides on asset management are readily available. Many of these definitions make little distinction between asset management and an asset management system considering both one and the same.

Deighton, though, makes a clear and concise distinction between asset management and an AMS. This is critical to the successful implementation of asset management and any subsequent implementation of an AMS in an agency.

Asset management for transportation agencies is not just a set of computer tools that enable the economic analysis of assets within and across all asset groups, but rather, a broad based business approach to managing assets that clearly **links** the **actions** of the transportation agency to **outcomes** (specific measurable goals and objectives) documented and published in the agency's transportation service strategic plan.

Any decision support software tools, that form the basis of an AMS, are considered only pieces of the broader asset management puzzle that assists decision makers to make better decisions with respect to their strategic transportation goals and objectives.

The difference between asset management and an AMS can best be thought of as follows:

"An agency practices asset management so it can deliver a transportation service to its community.

At the same time, an agency uses an asset management system so it can use a systematic practical approach to practicing asset management."³

To Deighton, the philosophy of asset management can be summarized as the business processes ensuring that all **actions** performed by the department are **linked** to desired **outcomes**.

The philosophy of an AMS can then be summarized as a management system that inventories, analyzes and demonstrates **outcomes** for alternative **actions**.

CDOT has established many asset management best practice initiatives within the department and the implementation of asset management best practice is not one of the primary purposes of this study or the proposed implementation framework, but Deighton believes that the distinction between asset management and an AMS is so crucial to an agency that it warrants mention in this document.

The proposed asset management framework documented in this report will assist CDOT in prioritizing funding across and within asset groups. Implementing dTIMS CT for strategic level asset management will enable CDOT

³ Zavitski, Jeffrey L., B.A., "Implementing a Strategic Highway Transportation Asset Management System in Utah", Presented at the 6th National Conference on Transportation Asset Management, November, 2005, Kansas City Missouri.

to evaluate outcomes for alternative actions (investment scenarios) for the assets included within the AMS, based upon:

- Unlimited number of assets or asset groups;
- Unlimited key performance measures (condition, environmental, economical, societal);
- Unlimited budget categories for investment (maintenance, preservation, rehabilitation, replacement);
- Unlimited budget scenarios to demonstrate the effects on the key performance measures based on alternative distributions of resources to the different budget categories and alternative funding amounts;
- Strategic Analysis Module slider based tools for illustrating the results of transferring funding from one asset group to another;
- True Cross Asset Analysis and Optimization for determining the best distribution of funding based on desired Key Performance Measures.

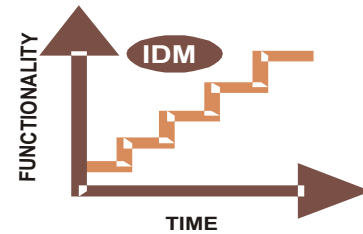
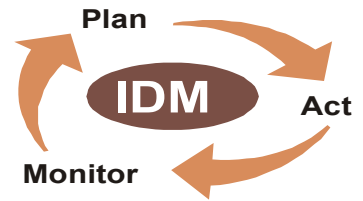
2.2 An Incremental Development Approach

Since inception Deighton has always prided itself on delivering solutions to transportation agencies that allow the agency to implement the Deighton tools (dROAD, dTIMS, dTIMS CT, dTIMS CT Enterprise) according to how that agency does business. Unlike a canned “black box” approach, Deighton never forces an agency into a specific approach, a specific set of required data or a specific analysis methodology. Nor does Deighton take an approach used in one agency, change the name and sell that exact approach to the next agency. Deighton has been successful over the last 23 years by tailoring an approach to a

project on an agency by agency bases and customizing our software tools through parameters and not through programming to meet the agency's needs.

A complex system that works is invariably found to have evolved from a simple system that worked... A complex system designed from scratch never works and cannot be patched up to make it work. You have to start over, beginning with a working simple system.⁴

Early on, Deighton recognized that simple systems can grow into quite sophisticated systems over time as small improvements are made. Somewhere between current practice and best practice in asset management is where an agency will define an appropriate level of sophistication for their asset management system. The move from current to appropriate is a journey that takes time and is accomplished by implementing a series of discrete incremental improvements known as Incremental Development Methodology (IDM).



Throughout the proposed implementation framework documented within this report, Deighton will make recommendations on the initial configuration for integrating the asset group data and models into dTIMS CT for the CDOT strategic analysis recognizing that the initial implementation will gain in sophistication through incremental development as the understanding and use of the system expands at CDOT and more and more is demanded from it.

⁴ Levy, H, Capability - Based Computer Systems, Digital Press, MA, 1984

2.3 Top Down / Bottom Up Asset Management

At its simplest description, an asset management system is a decision support tool composed of two main components, the asset management database and the asset management analysis. dTIMS CT has been designed to perform both these functions for strategic and tactical level asset management.

Deighton describes the implementation of asset management as a “top down / bottom up” approach featuring vertical and horizontal integration amongst the three levels of asset management planning: Strategic, Tactical, and Operational and across the different asset groups (pavement, bridge, maintenance...).

Figure 2 illustrates the integration across asset groups (pavement, bridges, signs, accidents, safety, mobility, etc.) and throughout the different planning levels (Stakeholders, Strategic, Tactical, and Operational).

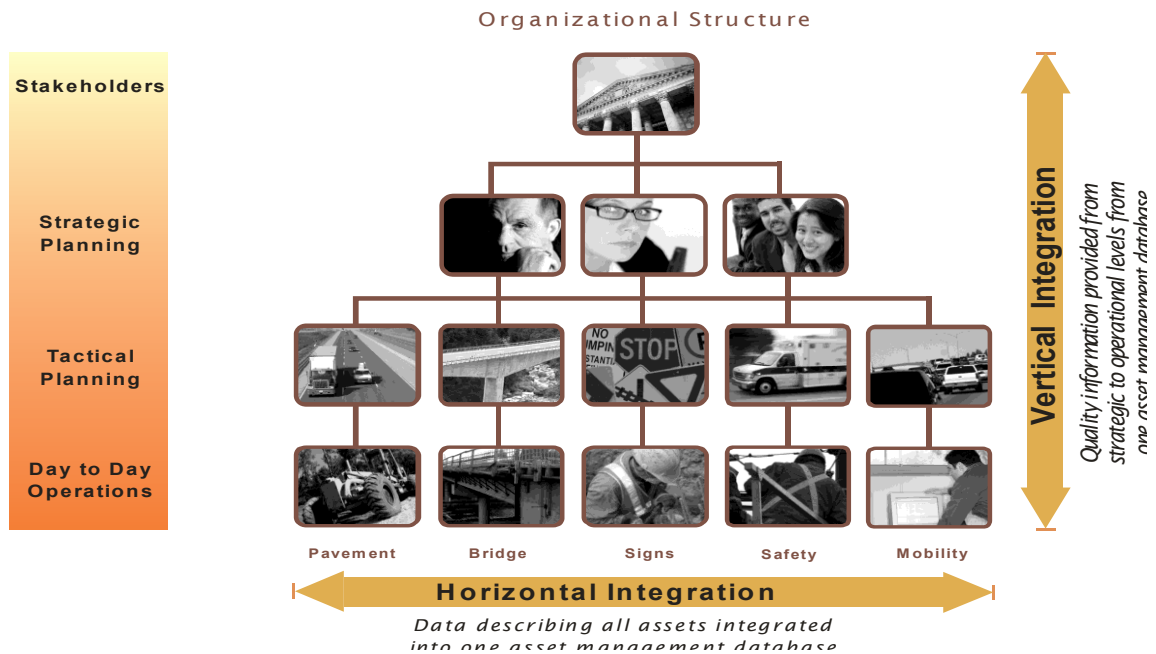


Figure 2: Asset Management System Integration

There are many important concepts illustrated within Figure 2 that require further explanation as they form the basis of the asset management implementation framework that Deighton is proposing to implement at CDOT.

2.3.1 Stakeholders

The Stakeholders are the ultimate users and owners of the transportation system that is maintained by CDOT. CDOT is responsible for providing transportation service that allows for safe, efficient and economical movement of people and freight throughout the state. A stakeholder can then be thought of as anyone who is directly or indirectly influenced by actions the department takes. Stakeholders are primarily represented by the State Legislature and the Transportation Commission at CDOT.

2.3.2 Strategic Asset Management

Strategic level asset management deals with managing the transportation network using a long-term strategic management approach and examines the network as a whole and not on an individual asset by asset basis. Strategic level asset management focuses on translating customer needs into providing a transportation service in a safe, efficient and economical manner.

At the strategic level, performance is measured in strategic terms where the impact of the transportation network on society, the economy and the environment (triple bottom line performance measures) are much more important than the condition and performance of any one individual asset. For example, put in simple terms, the transportation assets in the network might be maintained in near perfect condition but be underutilized if they do not take people where they want to go. Strategic level asset management relies on the

synergy of the transportation system where the system itself is considerably greater than the sum of its individual asset group components.

Strategic level asset management allocates resources (natural, physical, financial, etc.) across the entire transportation network where needed and expects tactical level asset management teams to use those allocated resources economically to achieve the overall strategic goals of the department by setting level of service requirements on the individual asset group components.

2.3.3 Tactical Asset Management

Tactical level asset management translates the strategic goals of the organization into specific goals and objectives for individual components of the transportation network. At the tactical level, managers are concerned with how their individual asset group contributes to the transportation system and how that component can be maintained in the most cost effective and beneficial manner to achieve performance targets in terms of levels of service.

Tactical asset management develops strategies that allocate resources (natural, physical, financial, etc.) to achieve the strategic goals of the organization by achieving defined levels of service as stated in the organization's Long Range Strategic Plan. The tactical asset management plans usually examine a mid range or 5 to 10 year time frame. From the Tactical Asset Management Plan, the short term (1-3) year operational plans are developed.

2.3.4 Operational Level Asset Management

Operational level asset management deals with short term planning and the day to day operations of the department. Asset management planning at the operational level develops action plans and short term plans (1-3) years that

achieve the required levels of service as outlined at the strategic and tactical levels.

If tactical asset management translates the strategic goals of the organization into mid – range plans to achieve the required levels of service for each asset group, then the operational level asset management can then be thought of as being short term strategies that, when examined in succession, will achieve the strategies outlined in the tactical level mid range plans.

2.3.5 Vertical Integration

The asset management framework relies on quality data and analysis results throughout all three asset management planning levels.

Strategic planning requires tactical and operational level data and models to ensure that policy decisions regarding levels of service are in fact realistic and attainable. Allocating resources at an overall strategic level based on social, economic and environmental factors cannot be completed without consideration of the impacts on the individual asset group levels of service.

Tactical level asset management requires strategic level data and models to ensure that tactical asset management plans meet level of service policies while still maintaining the overall strategic levels of service in terms of the triple bottom line performance measures. As well, tactical plans must be consistent with operational asset management capabilities to ensure that operations can translate the tactical asset management plans into reality over their consecutive operational asset management plan cycles.

Operational level asset management requires strategic level and tactical level asset management data and models to ensure that the consecutive short term

operational plans meet and achieve the strategic and tactical level of service goals.

The asset management database is a key component of the asset management framework that enables the vertical integration to take place. dTIMS CT as the asset management database allows unlimited user defined tables to store any asset management data regarding the transportation network. Once data is stored within the asset management database it can be integrated with asset data from any other asset group.

2.3.6 Horizontal Integration

Data integration between asset groups is a key component of asset management as tactical and operational asset management plans within one asset group can affect the levels of service within many other asset groups. CDOT currently has several data integration initiatives on-going within the department, so data integration is not a key component of the AMS framework presented within this report. That being said though, the data integration functions of dTIMS CT will certainly be required when bringing in data required for the strategic analysis.

2.4 Funding Needs and Tradeoffs

Figure 3 provides a more detailed examination of the asset management framework that is proposed for CDOT.

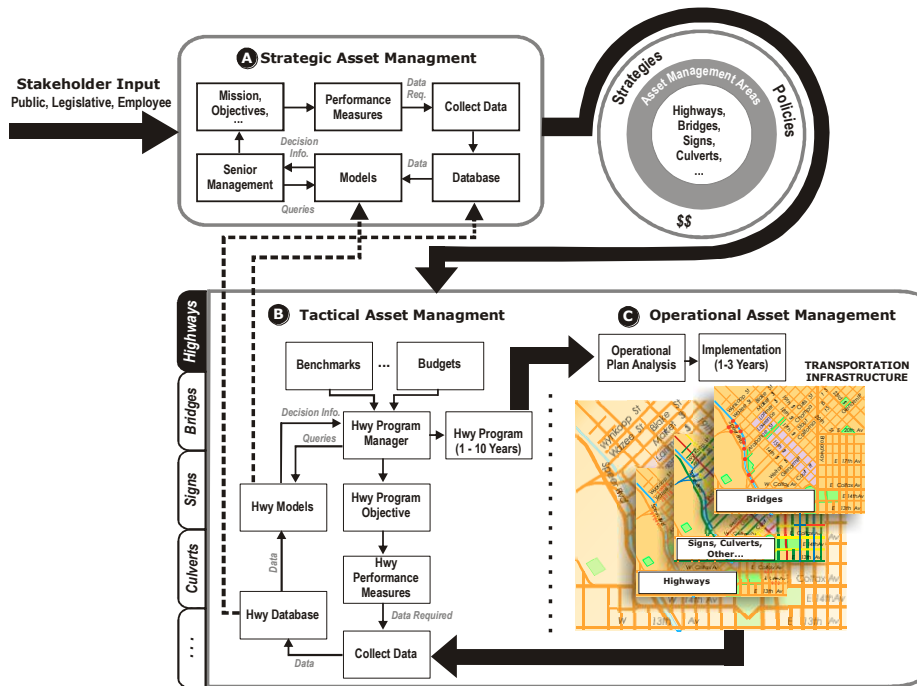


Figure 3: Advanced Asset Management Framework

2.4.1 Strategic Level Analysis

At the strategic level (A in Figure 3) an asset management analysis is completed using data and models passed in from the tactical and operational levels into dTIMS CT.

This data and models from the asset groups are supplemented with additional performance data that can be used to perform the strategic analysis using the triple bottom line approach. These two sets of performance measures, condition related from the asset groups and economic, societal, and environmental from the strategic level asset management data collection, are then analyzed and the results used to help set level of service guidelines, transportation policy and resource allocations (budgets) between the various asset groups within the department.

In the initial phases of the CDOT implementation, the strategic analysis will focus on providing the funding needs to maintain the asset groups at or above the current level of service guidelines established by CDOT policy. As more and more demands are placed upon CDOT by the stakeholders and as more and more external (other agencies within Colorado) and internal groups (within CDOT) are vying for less and less available state revenue funding, CDOT will need to expand the strategic analysis to more of a triple bottom line approach where funding allocation decisions are made based upon the overall benefit of the transportation network to the Colorado's economy, society and the environment as opposed to an analysis based entirely on condition based levels of service.

The results of the strategic analysis are the outcomes for various alternative investment strategies (Figure 4). Outcomes are reported in terms of the key performance measures used during the analysis through slider tools and graphic reports in dTIMS CT. The alternative investment strategies can include changes in total funding or the distribution of that funding in different budget categories and in different asset groups.

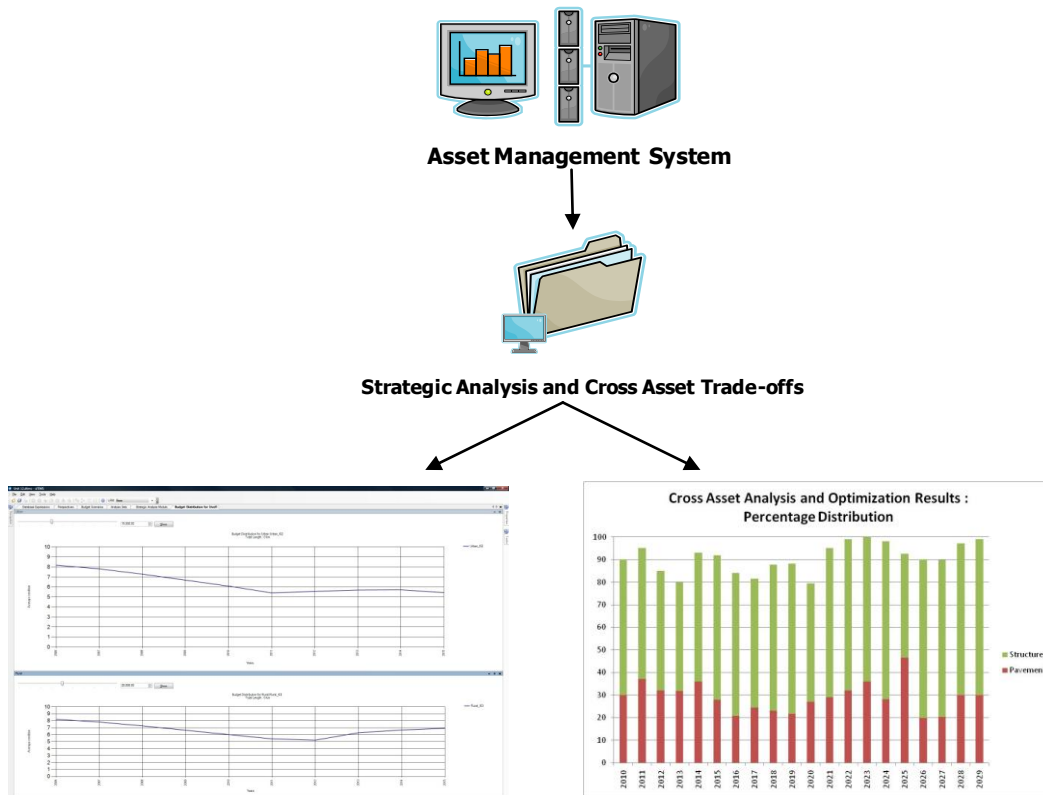


Figure 4: Asset Management Strategic Planning

2.4.2 Tactical Level

At the tactical level (B in Figure 3) the asset group analysis process begins with strategies, policies, directives and allocated resources resulting from the strategic analysis. Quite simply, the strategic level sets the level of service to be attained and the available dollars to be used to attain the set levels. After that, the tactical asset management groups can develop their respective asset management plans including their own strategies, objectives, performance measures and analysis models to develop the asset group program.

Within CDOT, the asset groups, for the most part, have a tactical level asset management system or initiatives in place to develop or acquire systems for asset

groups without a current system. Within the proposed implementation for CDOT, some assets may require a tactical level management analysis to be completed in dTIMS CT prior to those assets being included within the strategic analysis. For example, Fleet management does not currently utilize a management system analysis so the tactical level analysis is being proposed to be developed in dTIMS CT prior to the Fleet being included within the strategic analysis. As can be seen in the systems view of the AMS, the AMS includes the functionality to complete an asset group analysis for individual assets groups as well as the ability to analyze across asset groups.

2.5 The AMS from A Systems Viewpoint

As discussed in the previous sections, the approach to asset management available in dTIMS CT is a top down / bottom up approach. When looking at the actual asset management analysis implementation in dTIMS CT, that approach necessitates loading the data and models from the tactical asset management systems into dTIMS CT for the strategic analysis. These data and models can then be supplemented with strategic level performance measures for the strategic analysis.

In a typical tactical asset management system analysis such as a PMS (Figure 5), the data is integrated together within the respective management system. Once the data is aggregated for analysis; maintenance, preservation, rehabilitation and replacement strategies for the assets are generated and then various "what-if" budget scenarios are optimized to determine outcomes for the various budget scenario resources and budget category distributions.

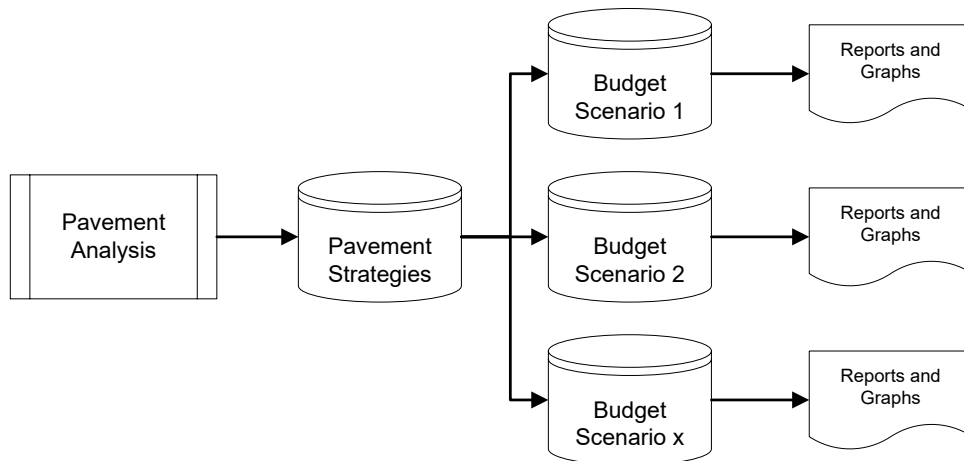


Figure 5: Typical Tactical Asset Management System Analysis

When the agency is satisfied with the results of the analysis and no more changes to the analysis parameters (key performance models, deterioration rates, treatment costs, etc.) are required, the results of the analysis for the selected budget scenario are then used to form the first-cut maintenance and rehabilitation plan for the asset and are used to generate projects for review and scoping prior to inclusion in the Long Range Plan or the Statewide Transportation Improvement Plan (STIP). The built in dTIMS CT reports and graphs are also used to report expected outcomes based on the budget amounts and distributions contained within the budget categories for any of the key performance measures included within the analysis.

In a strategic asset management analysis (Figure 6), data and models are imported from the respective asset groups and integrated together. Then for each asset group included within the analysis, strategies are generated in dTIMS CT (if necessary) or the strategies are imported (if available) from the respective tactical level asset management system and then the cross asset analysis and strategic analysis module slider tools are used to determine funding needs based on the outcomes from the actions analyzed (Figure 6).

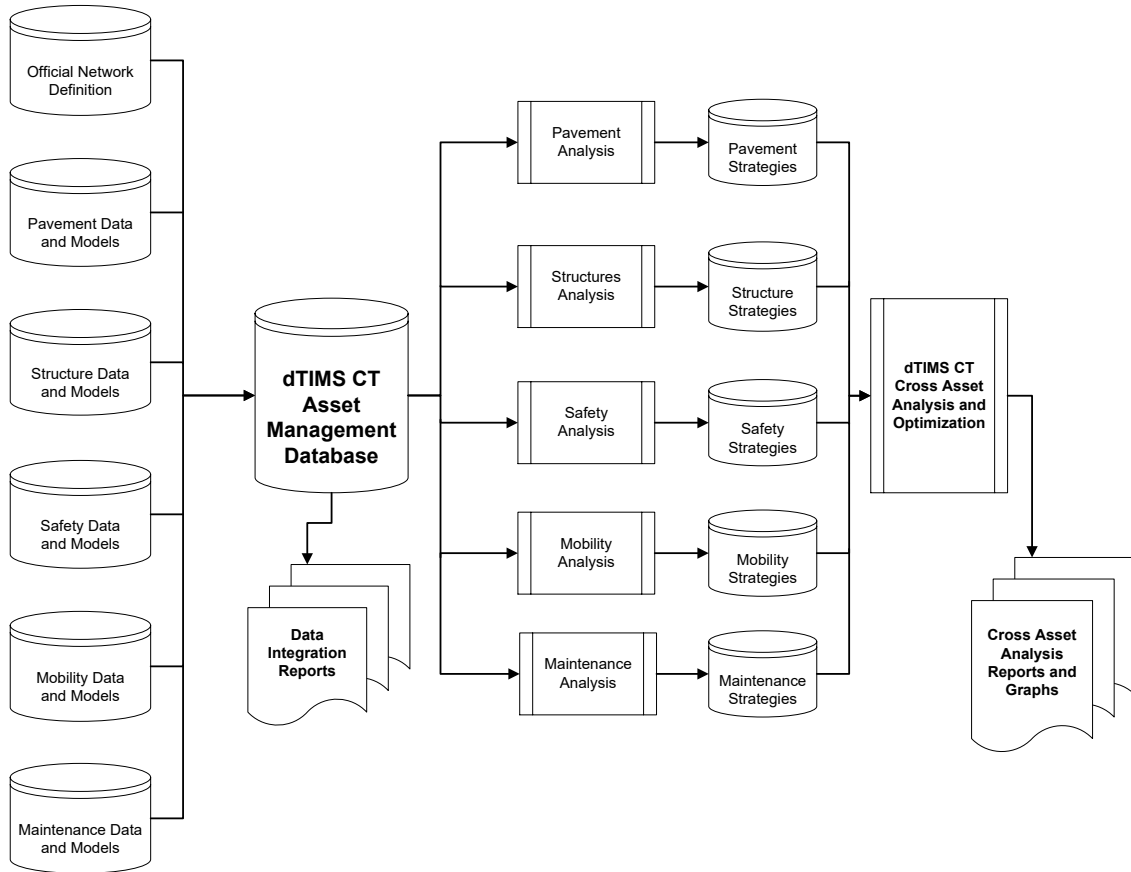


Figure 6: Typical Strategic Asset Management Analysis

Figure 6 displays the typical system framework for the strategic analysis being proposed at CDOT. Data and models are imported from the tactical level asset management system so that strategies can be generated in dTIMS CT and the economic trade-off analysis can be completed.

2.6 The AMS Analysis

The flexibility of dTIMS CT as an asset management system enables an agency to determine the level of analysis sophistication for each asset being analyzed and configure that level of sophistication within dTIMS CT through the extensive flexibility of the analysis parameters. The following subsections will discuss the

different types of analysis available within dTIMS CT so that these can be expanded for CDOT specific asset groups later in this report.

2.6.1 Asset Specific Analysis

In an Asset Specific Analysis, individual maintenance, preservation, rehabilitation and replacement strategies are generated and optimized for each asset in the asset group. This is the most sophisticated form of analysis available within dTIMS CT as it considers each asset individually and outcomes for the network are based on the optimized strategies for each of the individual assets included within the analysis. CDOT's PMS implemented in dTIMS CT uses an asset specific analysis where each pavement section is analyzed separately and the results summarized for the network based on maximizing the benefit to the network as a whole during the optimization.

In an asset specific analysis users can customize the level of sophistication of this analysis through the analysis parameters which can be completely customized for each asset. These parameters include:

- Performance measures (condition, use, classification)
- Deterioration models (site specific, family, deterministic, probabilistic)
- Treatments models (maintenance, preservation, rehabilitation, replacement)
- Treatment costing models
- Treatment trigger models
- Treatment reset and impact models
- Budget and Analysis parameters

For assets that currently do not have a tactical level management system (such as CDOT Fleet assets), the initial asset specific analysis can be configured with basic

models and basic parameters and then incrementally developed and enhanced over time to increase the level of sophistication of the analysis and the accuracy of the results.

2.6.2 Remaining Life Analysis

In a Remaining Life Analysis, all assets are analyzed individually based upon the age of the asset. The age of the asset increases each year and treatments and strategies are generated based upon the age only. In the future, a simple remaining life analysis can easily turn into an asset specific analysis as condition assessments and model development occurs.

2.6.3 Categorized Grouped Asset Analysis

In a categorized grouped asset analysis, assets are not analyzed individually but grouped into condition categories and analyzed by category. Assets are grouped into categories of Good, Fair and Poor and then simple aggregated deterioration rates, by quantity or by percentage, are used to deteriorate the assets from one condition category to the next. Treatments are configured to move a percentage of assets from one category to another category and optimization selects the best percentage to move each year based on the available budget. The higher the budget amount the higher the percentage of the assets that can be rehabilitated or replaced each year.

2.6.4 Grouped Asset Analysis

In a grouped asset analysis, assets are analyzed for replacement strategies only and all assets are analyzed in one group. dTIMS CT optimizes the number of assets that can be replaced each year with higher budget amounts increasing the

number of assets that can be replaced each year and decreasing the time it take to replace all of the assets.

2.6.5 Level of Service Budget Analysis

Maintenance activity budgeting typically works on level of service grades in relation to available funding. When this analysis is configured in dTIMS CT, each of the activities are loaded into dTIMS CT by area (region / district / planning area) and treatments generated to maintain each of the different levels of service over the analysis period. Optimization then is used to prioritize the activities and areas based on the available budget supplied to the optimization.

3. Implementing dTIMS CT for Strategic Analysis at CDOT

This section of the report will examine the implementation of dTIMS CT for Strategic Analysis at CDOT and outline for each asset group the resources to complete the initial implementation of the assets in dTIMS CT and maintenance of the asset management system going forward.

3.1 A Note About Data

Implementing the AMS within dTIMS CT will add new technology to the existing capabilities of CDOT for analysis and optimization. The purpose of the AMS is to increase capabilities for strategic analysis and optimization by leveraging data and models in existing systems not to replace any existing systems.

In order for the strategic analysis to be successful within the AMS, data and models from existing management systems must be loaded into dTIMS CT for analysis. Where possible, data will be supplied by Data Management through the IRIS database and imported into dTIMS CT. When required asset data is not contained within the IRIS database, dTIMS CT will link to existing systems (through ODBC and data transformation services) where possible and when linking is not possible, data exports and data imports will be completed.

3.2 Initial Asset Management System Configuration

As a starting point, the current CDOT PMS will be used for the initial configuration of the Asset Management System. The PMS databases will be used

for defining the current CDOT network definition and for the initial pavement management analysis component of the strategic analysis.

Deighton envisions that the strategic analysis using slider based tools and the cross asset analysis and optimization will be completed based on condition and levels of service only and will not include factors for the triple bottom line. These additional factors can be developed in future phases of the strategic analysis.

As other assets are added to the asset management system, additional perspective tables (data tables) will be added and the analysis configured as necessary, depending on the type of analysis being performed for each asset.

Once the initial configuration is completed, CDOT can then move forward to developing the data and models necessary to enhance the strategic analysis so that additional performance measures are considered.

The resource estimates (in hours) necessary for the initial AMS configuration and setup of dTIMS CT are shown in Table 1.

Task	Description	Deighton Staff Resources	Planning Staff Resources	Information Technology Resources	Pavement Management Resources
1.1	Deliver PMS to Deighton	0	0	2	2
1.2	Configure AMS based on CDOT PMS	64	0	0	0
1.3	Software Installation and Database Configuration	6	6	2	0
1.4	dTIMS CT Training	34	92	2	0

Table 1: Initial AMS Configuration Resources

The 92 hours for training consists of training for two users for 34 hours and 8 additional staff for 2 hours for an executive overview of the AMS.

Annual database maintenance includes shrinking and compacting the databases as well as backup / restore and disaster recovery archiving.

3.3 Integrating Pavement Management within the AMS

Pavement management planning and programming at CDOT begins with the integration of collected data within the DOT. The data is loaded and processed by the pavement management group over a two to three month time period culminating in a set of analysis sections to analyze in dTIMS CT.

Before the pavement management analysis is completed, the integrated data is used to calculate RSL and to calculate site-specific performance models and default family curves to use within the PMS analysis.

The pavement management analysis is generally completed using 4 different draft analysis results as follows:

- First Draft - Used to verify pavement type data and other data as well as adding completed projects that HQ is unaware of;
- Second Draft - Used to gather more feedback regarding projects and analysis and is reviewed internally only.
- Third Draft - Internal HQ and External Region review of the recommendations. Changes to curves and RSL values can be made at this time.
- Final Draft - Regions can make minor changes to the final list of projects, but CDOT Policy Memo 10 specifies the project match that must be attained by the regions with respect to the recommendations coming out of HQ.

As the Pavement Management System will form the basis of the AMS and is implemented in dTIMS CT already, very little initial work must be done and yearly maintenance will be minor.

The current CDOT network definition is maintained and updated within dTIMS CT by the pavement management staff on an annual basis and this definition will be loaded into the AMS when the update cycle by the pavement management staff is complete.

Required data from the PMS will also be loaded annually into the AMS for the pavement analysis component within the AMS. Changes to analysis parameters will also need to be maintained between the two systems, these analysis parameters include treatment costs, treatment triggers and deterioration models.

Task	Description	Deighton Staff Resources	Planning Staff Resources	Information Technology Resources	Pavement Management Resources
2.1	Configure PMS within AMS	24	4	0.0	4
2.2	Annual Network Updates to PMS Data	0	16	0.0	16
2.3	Annual Updates to PMS Models		24	0.0	24

Table 2: Pavement Management Integration Resources

Once implemented in dTIMS CT for Asset Management, the strategic analysis module (slider tools) can be utilized as well as the cross asset analysis and optimization functionality for funding needs and resource allocations.

3.4 Integrating Bridge Management within the AMS

Bridge Management at CDOT is completed through the use of manual inspections and semi-automated processes using PONTIS and other software packages.

Data collection and processing of bridge inspection data culminates in the NBI update report submission to the Federal Government in April of each year. Once the Federal Submission is completed Staff Bridge completes the planning and programming process for delivering the "Select List" and the "Allocation Program Report" to the CDOT Regions where final planning and programming is completed.

Projection Reports on system condition are completed using a custom model developed in Excel based on the Age of the Structures and based on the Average Replacement Age. The report assumes that all bridges will be replaced according to current code and projected capacity and geometric needs. The projection report specifies replacement and rehabilitation and does not include preventive maintenance.

Within the AMS, Deighton is proposing to initially implement the Remaining Life and Replacement model as currently implemented within the Excel Calculations performed by Staff Bridge.

Once the initial implementation is complete, CDOT may want to investigate using dTIMS CT for analyzing the structures at the component level (Deck, Superstructure and Substructure) or at the element level to aid in making funding allocation decisions and to aid in making planning and programming recommendations to the CDOT Regions.

The resource estimates for the initial configuration of the Bridge assets in the AMS are as follows:

Task	Description	Deighton Staff Resources	Planning Staff Resources	Information Technology Resources	Staff Bridge Resources
3.1	Develop Data Extraction Routines and data import routines	40	4	16	4
3.2	Configure Remaining Life Analysis for Bridges within AMS	100	24	0	24
3.3	Annual Network Updates to Bridge Data	0	8	8	8
3.4	Annual Updates to Bridge Models	0	16	0	16

Table 3: Bridge Management Integration Resources

Once implemented in dTIMS CT for Asset Management, the strategic analysis module (slider tools) can be utilized as well as the cross asset analysis and optimization functionality for funding needs and resource allocations. The remaining life analysis could also be expanded to include preventive maintenance and rehabilitation recommendations based on age of the structure once the initial replacement has been completed.

3.5 Maintenance Levels of Service

Maintenance Levels of Service budgets and targets are set based on 9 different Maintenance Program Areas and 15 Maintenance Sections consisting of 9 maintenance sections and 6 traffic areas. Budget processing begins in August of each year and usually ends 8 to 10 weeks later in October. Program Areas are assigned grades (A+ through D- and -F through F+) and MLOS staff calculates the budget amount to maintain each grade at the Program Statewide and at the Section level.

In order to integrate the MLOS budgeting into dTIMS CT, Deighton will implement a Level of Service Budgeting Analysis in dTIMS CT with data provided from MLOS staff at the Section Level. A sample of the data (major grades only) supplied by MLOS staff is shown in Table 4 for one the Greeley Maintenance Section:

Section	MPA	LOS	Budget	LOS	Budget	LOS	Budget	LOS	Budget	LOS	Budget	
Greeley Maint.	100	F	\$ 1,199,768.87	D	\$ 1,480,128.53	C	\$ 1,826,002.09	B	\$ 2,252,698.72	A	\$ 2,779,104.98	
	150	F	\$ 6,260,611.38	D	\$ 7,273,792.68	C	\$ 8,450,941.43	B	\$ 13,359,900.88	A	\$ 55,101,638.32	
	200	F	\$ 1,512,030.12	D	\$ 1,756,728.40	C	\$ 2,041,027.16	B	\$ 2,371,335.29	A	\$ 2,755,098.54	
	250	F	\$ 978,929.18	D	\$ 1,137,353.44	C	\$ 1,321,416.17	B	\$ 1,535,266.56	A	\$ 1,783,725.25	
	300	F	\$ 1,430,481.86	D	\$ 1,644,388.11	C	\$ 1,892,911.71	B	\$ 4,275,183.25	A	\$ 5,828,937.28	
	350	F	\$ 761,141.87	D	\$ 830,383.11	C	\$ 911,548.55	B	\$ 1,296,021.48	A	\$ 2,759,913.68	
	400	F	\$ 3,875,450.39	D	\$ 4,502,630.97	C	\$ 5,231,310.84	B	\$ 6,077,916.07	A	\$ 7,087,800.79	
	450	F	\$ 1,577,924.76	D	\$ 1,945,824.40	C	\$ 2,399,694.12	B	\$ 2,959,623.25	A	\$ 3,650,395.51	
	Section Total			\$ 17,596,338.43		\$ 20,571,229.64		\$ 24,074,852.07		\$ 34,127,945.50		\$ 81,746,614.35

Table 4: MLOS Budget Data for Greeley Maintenance Section

The analysis will be configured so that dTIMS CT will enable each program area and section to be maintained at each grade each year. The budgets supplied during the funding needs analysis and the asset trade-off analysis level optimization within the AMS through the slider tools and the cross asset analysis and optimization tools will then determine the outcomes for each section and program area. Once the analysis is complete, the budgets and goals for each MPA and Section can be transformed into the pavement management sections for reporting along specific corridors and for coordination with pavement management recommendations.

The resource estimates for the implementation of the MLOS service budget analysis in the AMS are as follows:

Task	Description	Deighton Staff Resources	Planning Staff Resources	Information Technology Resources	MLOS Staff Resources
4.1	Configure Level of Service Budget Analysis within AMS	120	8	0	8
4.2	Annual Network Updates to MLOS Data	0	16	0	16
4.3	Annual Updates to MLOS Models	0	8	0	8

Table 5: MLOS Integration Resources

3.6 ITS Management

ITS assets are managed using inventory and warehouse facilities provided within CDOT's SAP environment. Much like Staff Bridge, ITS relies on data extracts and manual processes to develop Capital Replacement Programs and Capital Replacement Budgets.

Implementation of the ITS assets within dTIMS CT for funding allocations and cross asset trade-offs will be similar to the bridge implementation within dTIMS CT where a remaining life analysis will be used.

Average replacement life for ITS assets can be determined using data from the SAP database, manufacturers' guidelines and staff expertise and implemented for each asset in dTIMS CT. An example of the information that can be obtained out of the SAP Equipment Master Database which will be used to develop replacement life for each asset is shown in the following figure:

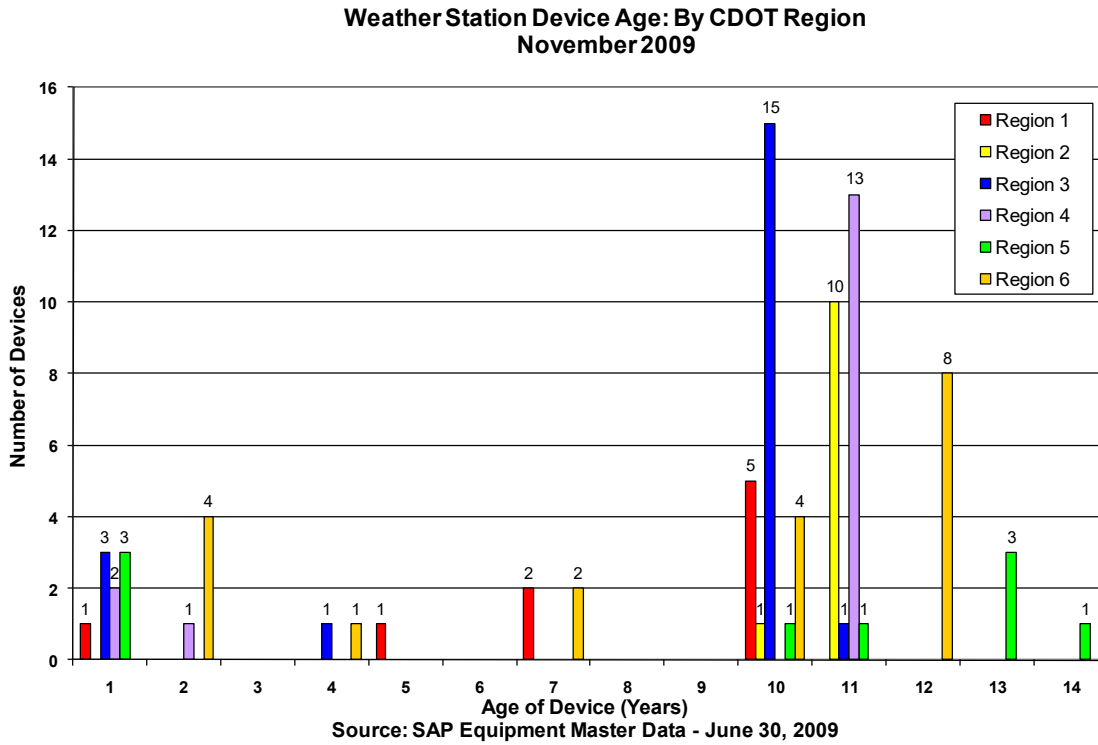


Figure 7: Example Device Age Report from SAP Equipment Master Database

The resource estimates for the initial configuration of the ITS assets in the AMS are as follows:

Task	Description	Deighton Staff Resources	Planning Staff Resources	Information Technology Resources	ITS Staff Resources
5.1	Develop Data Extraction Routines and data import routines	40	0	16	0
5.2	Configure Remaining Life Analysis for ITS assets within AMS	100	24	0	24
5.3	Annual Network Updates to ITS Data	0	8	8	8
5.4	Annual Updates to ITS Models	0	16	0	16

Table 6: ITS Asset Integration Resources

3.7 Fleet Management

During the initial framework development meetings, Deighton briefly discussed the implementation of Fleet Assets within dTIMS CT. Deighton believes that the implementation of the Fleet Assets within dTIMS CT could be used to help secure additional funding for the replacement of the aging fleet.

Using an analysis similar to the Remaining Life analysis proposed for bridges and ITS assets with the addition of maintenance cost and availability data, dTIMS CT can help illustrate the savings in maintenance costs and downtime by replacing an aging fleet.

The resources to configure the Fleet assets in dTIMS CT are as follows:

Task	Description	Deighton Staff Resources	Planning Staff Resources	Information Technology Resources	Fleet Staff Resources
6.1	Develop Data Extraction Routines and data import routines	40	0	16	0
6.2	Configure Fleet Remaining Life Analysis for Fleet Assets	120	24	0	24
6.3	Annual Network Updates to Fleet Data	0	8	8	8
6.4	Annual Updates to Fleet Models	0	16	0	16

Table 7: Fleet Asset Integration Resources

3.8 Initial Asset Management Analysis

Once the assets have been selected for the initial implementation and configured within dTIMS CT, the strategic analysis parameters will need to be configured within dTIMS CT. When the parameters are configured, the analysis can be executed and the analysis results reported.

The resource estimates for configuring the initial strategic analysis within dTIMS CT are as follows:

Task	Description	Deighton Staff Resources	Planning Staff Resources	Information Technology Resources
7.1	Configure Analysis Sets and Budget Scenarios for Strategic Analysis	16	8	0
7.2	Configure Strategic Analysis Module	8	4	0
7.3	Configure Cross Asset Analysis and Optimization Module	8	4	0
7.4	Execute the Strategic Analysis, test, and refine parameters as necessary	56	4	0
7.5	Report Results and produce implementation final report	120	24	0

Table 8: Fleet Asset Integration Resources

3.9 Annual Asset Management Analysis

Once the analysis has been configured within dTIMS CT, Planning Staff will then be responsible for the annual tasks of loading data, updating parameters, running the analysis and producing the reports for resource allocation and asset trade-offs.

The nature and complexity of any requests from internal sources (Budget and Finance, Planning, etc.) and the timing and current stage of the planning cycle within CDOT will determine the amount of analysis runs that are completed within the AMS.

In the initial stages of the AMS, the strategic analysis module and the cross asset trade-offs will be based on the condition of the assets and the benefits and costs of maintaining those conditions without consideration of other factors.

In the future, other factors such as those previously mentioned (environmental, economical, and societal factors) may need to be developed to make more accurate resource allocation decisions and the annual maintenance requirements of the AMS may change as new data is added to the system and new models developed. The data required for the initial analysis exists in the systems where data is linked or extracted, but if new data is to be gathered and collected against existing assets, that data will need to be stored within the AMS or within the respective management system for the underlying asset.

Initially Deighton estimates the annual maintenance and analysis resources required for the AMS as follows:

Task	Description	Deighton Staff Resources	Planning Staff Resources	Information Technology Resources
8.1	Updating Strategic Analysis (slider tools) parameters	0	40	0
8.2	Updating Cross Asset Analysis and Optimization parameters	0	40	0
8.3	Executing the Analysis	0	200	0
8.4	Extracting Analysis Results for Reports	0	40	0
8.5	Database Maintenance	0	24	24
8.6	Extended AMS Support	120	0	0

Table 9: Annual Asset Management Maintenance and Analysis Resources

4. Conclusions

4.1 Analysis Outcomes

When the analysis is configured for each asset within dTIMS CT, CDOT can execute both a tactical analysis for each asset and a strategic analysis where the asset can be included with other assets implemented within dTIMS CT.

At the tactical level, the AMS will generate, optimize and report recommended strategies for each asset group consisting of multiple treatments over the time period being analyzed. For each asset group, the type of analysis being implemented and the level of that implementation will determine the type of tactical level strategies that result. As an example, consider the implementation of the bridge assets in dTIMS CT. If the bridges are implemented as initially envisioned within this document, the initial analysis will output funding needs and strategies based on bridge replacements only. In future phases, preventive maintenance, minor repair and major rehab treatments could be added to the bridge analysis to increase the sophistication of the analysis.

The Strategic Analysis capabilities of dTIMS CT are dependent upon on the tactical asset management analysis completed for each asset group.

The strategic analysis module (slider tools) specifies various budgets for each tactical level asset group analysis and then presents the results in graphical format with sliders for the user to adjust funding and see the impacts of funding decisions.

The Cross Asset Analysis and Optimization functionality of dTIMS CT optimizes all of the strategies from the tactical level analysis at once as a whole. The more sophisticated the tactical level analysis, the more sophisticated the results of the strategic analysis.

The following table summarizes the type of analysis implemented for each asset group and indicates the level of detail that will be included in the initial phases of the AMS implementation.

Asset Group	Type of Analysis	Level of Service Only	Preventive Maintenance	Rehab or Repair	Replacement
Pavement	Asset Specific Analysis		X	X	X
Bridge	Asset Specific - Remaining Life				X
MLOS	Level of Service	X			
ITS	Asset Specific - Remaining Life				X
Fleet	Asset Specific - Remaining Life				X

Table 10: Asset Analysis Summary

As the implementation of the AMS continues in the future and as tactical asset management systems are implemented for the Bridge, ITS and Fleet assets, the level of detail in terms of available treatment recommendations should increase.

4.2 Summary of Resource Estimates

In order to present a total view of the resource estimates required to implement that initial version of the AMS, the resource estimates from the previous section have been amalgamated together and presented in the following table.

Initial Asset Management System Configuration									
Task	Description	Deighton	Planning	IT	Pavement	Bridge	MLOS	ITS	Fleet
1.1	Deliver PMS to Deighton	0	0	2	2	0	0	0	0
1.2	Configure AMS based on CDOT PMS	64	0	0	0	0	0	0	0
1.3	Software Installation and Database Configuration	6	6	2	0	0	0	0	0
1.4	dTIMS CT Training	34	92	2	0	0	0	0	0
Configuring Pavment Assets within AMS									
Task	Description	Deighton	Planning	IT	Pavement	Bridge	MLOS	ITS	Fleet
2.1	Configure PMS within AMS	24	4	0	4	0	0	0	0
2.2	Annual Network Updates to PMS Data	0	16	0	16	0	0	0	0
2.3	Annual Updates to PMS Models		24	0	24	0	0	0	0
Configuring Bridge Assets within AMS									
Task	Description	Deighton	Planning	IT	Pavement	Bridge	MLOS	ITS	Fleet
3.1	Develop Data Extraction Routines	40	4	16	0	4	0	0	0
3.2	Configure Remaining Life Analysis for Bridges	100	24	0	0	24	0	0	0
3.3	Annual Network Updates to Bridge Data	0	8	8	0	8	0	0	0
3.4	Annual Updates to Bridge Models	0	16	0	0	16	0	0	0
Configuring MLOS Assets within AMS									
Task	Description	Deighton	Planning	IT	Pavement	Bridge	MLOS	ITS	Fleet
4.1	Configure Level of Service Budget Analysis	120	8	0	0	0	8	0	0
4.2	Annual Network Updates to MLOS Data	0	16	0	0	0	16	0	0
4.3	Annual Updates to MLOS Models	0	8	0	0	0	8	0	0
Configuring ITS Assets within AMS									
Task	Description	Deighton	Planning	IT	Pavement	Bridge	MLOS	ITS	Fleet
5.1	Develop Data Extraction Routines	40	0	16	0	0	0	0	0
5.2	Configure Remaining Life Analysis for ITS	100	24	0	0	0	0	24	0
5.3	Annual Network Updates to ITS Data	0	8	8	0	0	0	8	0
5.4	Annual Updates to ITS Models	0	16	0	0	0	0	16	0
Configuring Fleet Assets within AMS									
Task	Description	Deighton	Planning	IT	Pavement	Bridge	MLOS	ITS	Fleet
6.1	Develop Data Extraction Routines	40	0	16	0	0	0	0	0
6.2	Configure Fleet Remaining Life Analysis for Fleet	120	24	0	0	0	0	0	24
6.3	Annual Network Updates to Fleet Data	0	8	8	0	0	0	0	8
6.4	Annual Updates to Fleet Models	0	16	0	0	0	0	0	16
Initial AMS Analysis Configuration									
Task	Description	Deighton	Planning	IT	Pavement	Bridge	MLOS	ITS	Fleet
7.1	Configure Analysis Sets and Budget Scenarios	16	8	0	0	0	0	0	0
7.2	Configure Strategic Analysis Module	8	4	0	0	0	0	0	0
7.3	Configure Cross Asset Analysis and Optimization	8	4	0	0	0	0	0	0
7.4	Execute the Strategic Analysis, test	56	4	0	0	0	0	0	0
7.5	Report Results and produce final report	120	24	0	0	0	0	0	0
Initial Implementation Resources		896	366	78	46	52	32	48	48
Subsequent Annual AMS Analysis Resources									
Task	Description	Deighton	Planning	IT	Pavement	Bridge	MLOS	ITS	Fleet
8.1	Updating Strategic Analysis	0	40	0	16	16	16	16	16
8.2	Updating Cross Asset Analysis and Optimization pa	0	40	0	16	16	16	16	16
8.3	Executing the Analysis	0	200	0	0	0	0	0	0
8.4	Extracting Analysis Results for Reports	0	40	0	0	0	0	0	0
8.5	Database Maintenance	0	24	24	0	0	0	0	0
8.6	Extended AMS Support	120	0	0	0	0	0	0	0
Subsequent Year Implementation Resources		120	344	24	32	32	32	32	32

Table 11: Summary of Resource Estimates