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ASSET MANAGEMENT IMPLEMENTATION PLAN AND TIERED SYSTEM PROCESS

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September 2001

COLORADO DEPARTMENT OF TRANSPORTATION
RESEARCH BRANCH

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16. Abstract
This study has developed a five-year transportation asset management plan for the Colorado Department of Transportation (CDOT). This study has also developed a proposed tiering structure of the state highway system to support asset management. Asset management represents a strategic approach to managing transportation infrastructure. It embodies a set of principles to improve how an agency conducts business, how it reaches decisions, and how it processes, uses, and communicates information. CDOT, in consultation with the Colorado Transportation Commission, has already taken a number of steps toward improved asset management. A unique Investment Category approach organizes program investments within a policy-oriented framework incorporating explicit measures of performance. Other steps taken by CDOT include updates of the statewide planning process and the program prioritization process, establishment of maintenance program levels of service, institution of customer surveys, and updates of relevant information technology applications. The recommended transportation asset management plan builds upon these established concepts, methods, information, and tools to propose specific actions over the next five years in the following areas: (1) completion of all elements of the Investment Category structure; (2) incorporation of asset management principles in CDOT's planning and programming processes, building on a tiered structuring of CDOT assets that has also been recommended in this study; (3) integration of asset management information on a GIS platform, and renewal of Information Technology strategic planning to support asset management department-wide; and (4) strengthening of program delivery mechanisms and measures. The recommended tiering of the state highway system is built around the concept of interregional corridors, because CDOT is the sole provider of significant interregional highway transportation.

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Executive Summary

ES.1 Asset Management Overview

Asset management represents a strategic approach to managing transportation infrastructure. It embodies a philosophy that is comprehensive, proactive, and long-term, with the following goals:

- To build, preserve, operate, and reinvest in facilities more cost-effectively with improved performance;
- To deliver to an agency's customers the best value for the dollar spent; and
- To enhance CDOT's credibility and accountability in its stewardship of transportation assets.

Asset management provides a set of principles that guide an agency in improving how it conducts business, how it reaches decisions, and how it processes, uses, and communicates information related to the management of its infrastructure. At its core, asset management focuses on an agency's allocation and utilization of resources – funding, people and skills, and information. It provides an integrated framework that establishes common approaches across asset classes in planning, program development, and program delivery. It encourages a number of best practices in these processes: e.g., consideration of the full range of alternatives at each stage of decision, adoption of a long-term view in economic analysis of projects, evaluation of tradeoffs across programs, monitoring of program delivery and system performance, and effective use of management and information systems throughout the infrastructure management cycle. Asset management is results-oriented, driven by policy goals and objectives with clear measures of system performance and accountability.

ES.2 CDOT Accomplishments to Date

CDOT, in consultation with the Colorado Transportation Commission, has already taken a number of steps toward improved asset management. A major development has been the establishment of its Investment Category structure, which organizes program investments within a policy-oriented framework identifying explicit measures of performance. CDOT's Investment Category structure is unique among state DOT practice nationwide:

- The Investment Category structure integrates several elements critical to asset management within a coherent, overarching framework;
- It structures investments based upon policy objective and impact on performance rather than funding source; and
- It facilitates the analysis of tradeoffs among capital, maintenance, and operations program categories.

The Investment Category structure establishes the unifying framework for communicating a vision of asset management at CDOT, and provides a foundation for the Asset Management Plan recommended in this study. The Investment Category structure is not the only advance that has been undertaken by CDOT, however. Other CDOT accomplishments complement the Investment Category approach, including updates of the statewide planning process and the program prioritization process, establishment of maintenance program levels of service, institution of customer surveys, and updates of relevant information technology applications.

ES.3 Asset Management Plan for CDOT

This Asset Management Plan builds upon these established concepts, methods, information, and tools to propose specific actions over the next five years to build upon and expand these accomplishments. Hallmarks of this vision include the following:

1. Completion of all elements of the Investment Category structure;

2. Incorporation of asset management principles in CDOT's planning and programming processes, building on the tiered structuring of CDOT assets recommended in this study;

3. Integration of asset management information on a GIS platform, and renewal of Information Technology strategic planning to support asset management department-wide; and

4. Strengthening of program delivery mechanisms and measures.

Each of these four areas entails multiple tasks that will need to be accomplished. An outline of these tasks follows, with recommended organizational responsibility, timeframe, and estimated budget amount. Timeframes are identified as near-term (accomplish in one to two years), mid-term (accomplish in three to four years), and long-term (accomplish in five years or longer). Budget figures identify total estimated cost, if applicable, to fund one or more projects associated with an objective or task. These costs are additional to those that may already be planned by CDOT. The objectives and tasks below constitute the key elements of CDOT's Transportation Asset Management Plan.

While the tasks are organized by area for clarity, in fact they will interact with each other across areas. For example, performance measures defined in the Policy area need to be incorporated in the systems and tools discussed in the Information and Analytic area, so that they can be applied to tradeoff analyses and decisions in the Planning and Programming area.

Policy and Institutional Recommendations

Asset Management Objective *CDOT Unit Responsible*	**Task**	**Timing and Cost**
A. Designate a departmental task force under the Deputy Director to guide implementation of the asset management plan. *Director*	1. Designate the task force, building upon the experience of the Project Panel for Asset Management Plan development.	Near-term
B. Complete and refine Investment Category goals, targets, and performance measures *DTD*	1. Complete definition of statewide goals, targets, and performance measures for all programs. 2. Discuss the completed approach with local and regional planning agencies.	Near-term Near-term
C. Fold the performance measurement of all programs, including future strategic ("7th pot") projects, within the Mobility, Safety, and System Quality Categories *DTD*	1. Apply established performance measures to identify impacts of all projects, including strategic projects. 2. Implement procedures on a trial basis, assess results, discuss with Transportation Commission, and finalize.	Near-term Near-term
D. Define state interest in non-state-owned infrastructure. *EMT*	1. Identify and categorize non-state-owned assets in which CDOT has an interest. 2. Review potential investment policies with Transportation Commission	Mid-term Mid-term
E. Improve public and internal understanding and support of asset management techniques. *Deputy Director*	1. Hold periodic departmental workshops to discuss asset management and its implications for department activities. 2. Develop and distribute public information describing asset management and its importance. 3. Track public perceptions of, and satisfaction with, asset management performance through customer surveys.	Near-term Near-term $75,000 Mid-term

Planning and Programming Recommendations

Asset Management Objective *CDOT Unit Responsible*	**Task**	**Timing and Cost**
A. Implement tiered classification of transportation assets. *DTD*	1. Implement recommended tiered system on a trial basis in cooperation with local and regional agencies. 2. Implement final set within planning and programming procedures and management and information systems.	Mid-term Long-term $500,000
B. Develop more complete scope and cost information for STIP projects (coordinate with Program Delivery) *OFMB*	1. Work with Regions to define a process and information needs. 2. Implement by 2004.	Mid-term, $250,000 Mid-term
C. Strengthen application of performance measures. *Deputy Director, Chief Engineer, DTD, Asset Managers, Maintenance & Operations*	1. Develop consistent measures across Investment Categories and programs serving common goals (e.g., safety, pavement/ maintenance, bridge/maintenance) 2. Develop specialized tools for tradeoff analyses and promote greater integration among management system and data 3. Develop or adapt applications to predict customer impacts in terms of user costs.	Near-term Near- to Mid-term, $1,000,000 Long-term, $250,000
D. Review over time those program allocations based on formulas to ensure consistency with performance-based asset management *Deputy Director*	1. Perform the following: • Identify program components subject to “fixed” or “formula” distributions. • Analyze implications across Regions and TPRs, comparing formula distributions versus implied distributions based upon performance measures. • Discuss comparison with Transportation Commission, CDOT managers, local and regional agencies. • Implement recommended changes.	Long-term, $250,000

Program Delivery Recommendations

Asset Management Objective *CDOT Unit Responsible*	**Task**	**Timing and Cost**
A. Strengthen tracking of program delivery and major project changes (coordinate with Planning and Programming). *Deputy Director*	1. Develop program tracking methodology and system based upon more complete initial cost and scope estimates.	Mid-term, $350,000
	2. Establish a program review team to meet periodically to review and approve major changes in scope, time, and cost.	Mid-term
B. Ensure consistency of accomplishments with program estimates of PMS, BMS, and MMS *Chief Engineer*	1. Reinforce procedures to define projects by employing information from management systems.	Mid-term
	2. Expand project delivery reports to confirm specific project treatments applied, or reasons for deviation	Mid-term

Information and Analytic Recommendations

Asset Management Objective *CDOT Unit Responsible*	**Task**	**Timing and Cost**
A. Meet end-user needs for complete, accurate, timely information. *Chief Engineer*	1. Conduct QA/QC checks to achieve reliable, credible management system operation and predictions	Near-term
	2. Schedule training of asset management staff to become more familiar with full range of PMS, BMS, MMS capabilities and to make better use of existing system capabilities	Near-term, $50,000
	3. Fill analytic gaps with simple, quick, economical tools.	Near- to Mid-term, $200,000
B. Enhance Information Technology (IT) support for asset management in CDOT. *Deputy Director*	1. Reconstitute the ITRT to provide high-level guidance for asset management.	Near-term
	2. Charge the ITRT to develop and implement an IT plan for asset management (e.g., to guide system integration and new system development)	Near-term
C. Integrate asset management system data on CDOT's GIS. *ITRT*	1. Details to be developed in IT plan, including: • Classification of assets in a tiered structure; • Integrated condition and performance measures, referencing systems, data sources; • Program and project information to be displayed on GIS; and • System capabilities: displays, queries, reports.	Mid- to Long-term; must be coordinated with other GIS objectives; potential cost is at least several million dollars, not exclusively for asset mgmt.

ES.4 Near-Term Implementation

The near-term tasks identified above present opportunities for immediate accomplishment as CDOT begins implementation of the Asset Management Plan. Many of these items are organizational and procedural in nature, and build upon the considerable work that CDOT has already done to promote better asset management. These near-term tasks will enable CDOT to engage all organizational units and levels of the Department in the asset management philosophy, and to lay the groundwork for the more strategic management processes, perspectives, and tools that will be needed in the future. Key near-term task objectives for CDOT include the following:

- To organize a task force chaired by the CDOT Deputy Director to provide leadership, demonstrate executive buy-in, guide and coordinate actions department-wide, and provide a focal point for strategic direction and communication of objectives and accomplishments.

- To complete the Investment Category structure to provide the goals, targets, performance measures, and analytic tools needed to use it to full advantage in planning, program development, and system monitoring.

- To communicate "what is asset management" and related CDOT actions to CDOT employees and to the Transportation Commission, stakeholders, and the public.

- To make better use of existing information technology (IT) where possible, and to develop new IT applications and tools where needed to support asset management. This objective is critical to the long-term success of asset management and comprises a number of tasks that could entail significant cost for development of IT applications and tools. A blend of organizational, planning, and developmental tasks is therefore proposed with respect to this objective:

  – To reconstitute the Information Technology Resource Team (ITRT) to provide high-level IT expertise to the Asset Management Task Force and to represent CDOT "customers" of IT applications and information.

- To charge the ITRT with developing an Information Technology Plan that specifically addresses IT support of asset management. A key aspect of this plan would include proposed steps for renewal or redevelopment of legacy systems, and integration of systems in a geographic information system (GIS) platform.
- To make "better and smarter use" of existing CDOT systems and data. This recommendation includes training to familiarize CDOT staff with existing system capabilities that are now underutilized but that are very relevant and helpful to asset management. It also encompasses a testing and validation phase for new or redeveloped systems to ensure that they provide credible information and can be used reliably in asset management business processes.
- To complement existing or proposed management systems with specialized analytic tools that provide needed functionality for asset management and that are quick and economical to develop and apply.

ES.5 Tiering of Assets

As an initial step toward asset management implementation, this study has also recommended an approach to create tiers of assets. Asset tiering recognizes that transportation assets serve different local, regional, and national needs that justify different levels of service. Stratifying these assets helps to organize resource allocation priorities and tradeoffs, propose meaningful target values of level of service, and provide a context for tracking expenditures, benefits, and other consequences of investments.

A major class of infrastructure assets in terms of public visibility and share of program budget is the state highway system. An existing basis of tiering of these assets is provided by Federal-Aid functional classes: Interstate highways, non-Interstate National Highway System (NHS) highways, and Other highways. This study proposes the following additional tiers to build on existing functional class:

- Connectivity role: Intraregional, interregional, or both;

- Level of use in terms of intervals of traffic volume;
- Role in freight carriage: classification or level of truck usage; and
- Role in transit use.

Classification tiers have already been proposed for other modal assets. It is proposed that these proposals be retained at this time without change until discussed further or formally adopted by the Transportation Commission.

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1.0 Introduction

1.1 Study Objectives, Tasks, and Scope

In April 2000, the Colorado Department of Transportation (CDOT) engaged the team of BRW, Inc., and Cambridge Systematics, Inc., to conduct a study entitled, ***Development of an Asset Management Implementation Plan and a Tiered System Process for CDOT***. The objectives of this study are to review current practices in transportation asset management at CDOT and among other DOTs that are "leaders" in the field, and to develop from this information a *CDOT Asset Management Plan* and a *Tiered System Process*. This Final Report documents the results of this study.

The study comprises five major tasks:

- **Task A – Review Asset Management as Now Practiced at CDOT**. This review encompasses CDOT's organizational responsibilities, procedures, and systems for planning, program development, allocation of resources, program delivery, facility monitoring, and reporting internally and to the Transportation Commission and the public.

- **Task B – Review Asset Management as Practiced in Five Leadership States**. Leadership states selected for interviews include Arizona, California, New York, Pennsylvania, and Washington State. These states have significant transportation infrastructure serving a range of customer needs in diverse conditions of climate and terrain, and are actively pursuing improved asset management techniques.

- **Task C – Develop a Tiered Structure of CDOT Transportation Assets**. Transportation assets serve different needs and justify different levels of service in a state with as diverse a terrain, climate, demography, and degree of urbanization as Colorado. Stratifying these assets within tiers helps to organize investment choices, priorities, and tradeoffs, establish target levels of service, and track expenditures, benefits, and other consequences of investments.

- **Task D – Develop an Asset Management Plan for CDOT**. The Plan has three components:

  - **Vision Statement –** A Vision of CDOT asset management, including its objectives, functions, and procedures, supporting management systems and data sources, and current CDOT accomplishments that provide a foundation for future development;
  - **Examples –** Examples of how asset management is applied in programming and budgeting decisions that illustrate its operation and its advantages, and provide insights into how to tailor and implement the Plan; and
  - **Implementation Program –** The implementation program encompasses a projected schedule, phasing of tasks, suggested performing unit, targets and milestones, projected benefits, and estimated budget costs.

- **Task E – Prepare Final Report and Briefing Presentation**. The final report and PowerPoint briefing presentation communicate the results of the tasks above.

The scope of the study encompasses primarily **state-owned transportation infrastructure**, representing transportation networks, structures, and associated features for which CDOT has direct ownership and operating responsibility. These facilities include state roadways, bridges, pedestrian ways, bicycle lanes, and a rail line that are on the state system.

There is also a category of **state-interest transportation infrastructure**, representing other transportation facilities in which CDOT maintains an interest due to legal or funding arrangements or the direct relevance of these facilities to statewide transportation (evaluated on a case-by-case basis). Examples of these facilities include off-system bridges, which are inspected by CDOT personnel; intermodal facilities that are judged to benefit the CDOT system; and aviation facilities that are funded through CDOT's Aeronautics Division. These infrastructure elements will be discussed when appropriate to asset management. However, since most critical decisions and tradeoffs by CDOT relate to the state-owned infrastructure component, it is the state-owned facilities that will receive most attention in this report.

While CDOT exercises management responsibility for the state-owned facilities, the scope and direction of its asset management role are circumscribed and influenced by several political, legal, and institutional relationships. Policy guidance and decisions affecting funding, options, and priorities in asset management are promulgated by a number of governing authorities, including the Colorado Transportation Commission, the Governor and State Legislature, and applicable state and federal administrative and regulatory bodies. Transportation plans and programs regarding state-owned facilities must be developed in cooperation with Colorado's metropolitan planning organizations (MPOs) and transportation planning regions (TPR), and be informed by public opinion. A number of public and private users depend upon the statewide transportation system for social, commercial, and recreational purposes, including local motorists and transit riders, freight carriers, service industries, public service organizations, and tourists. CDOT must be responsive to its customers, and regularly engages in outreach efforts to gauge public perceptions and degree of satisfaction with its services. Thus, while this study focuses on CDOT roles and responsibilities in asset management, it recognizes the broader institutional environment and set of interests that CDOT must respond to.

Within this institutional context, the Colorado Transportation Commission has expressed significant support for asset management. This support has been evident in both the encouragement to CDOT to undertake this study and in the comments received at the briefing to the Commission on study findings and recommendations. The CDOT Executive Management Team has likewise offered helpful comments and support during briefings and workshops on asset management, as well as in interviews with individual members of the EMT. The potential roles that can be played by the Transportation Commission and the EMT in advancing better asset management practice are outlined in Section 4.0.

1.2 Report Organization

The report organization responds to and builds upon the project tasks above.

- **The remaining parts of Section 1.0 introduce the topic of transportation asset management**. They summarize principles and characteristics of asset management,

summarize related work to date in the U.S. and internationally, and outline current accomplishments and challenges of implementing asset management within a U.S. public sector transportation agency.

- **Section 2.0 summarizes current asset management practice at CDOT**. It describes the characteristics of the statewide transportation system, CDOT's organizational and program structure, and the policies, processes, and decision-support tools relating to asset management.

- **Section 3.0 reviews transportation asset management practices in peer agencies**. This review encompasses State DOTs that are taking the lead in this formative era of transportation asset management in the U.S., and establishes useful examples and points of comparison for developing the CDOT Transportation Asset Management Plan.

- **Section 4.0 recommends the CDOT Transportation Asset Management Plan**. This section comprises a Vision Statement, Examples of Specific Asset Management Improvements, the overall CDOT Asset Management Plan, and an Implementation Plan for near-term items.

- **Section 5.0 presents a Tiered System for CDOT transportation infrastructure assets**. Applying the results of peer state comparisons and input from a focus group conducted by the Project Team, it develops an approach to organizing and classifying CDOT's transportation infrastructure assets.

1.3 Transportation Asset Management

Related Work to Date. Asset management has been studied by overseas transportation and public works agencies for several years. Detailed methodological handbooks and reports have been produced, for example, in Australia and New Zealand. The subject is currently receiving considerable attention throughout the developed world, as evidenced by a recently completed compendium by the Organization for Economic Cooperation and

Development (OECD) of activities of its member nations in North America, Europe, and Asia.

Within the United States, the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) began sponsoring a series of workshops on asset management beginning in 1996. Subsequently, AASHTO appointed a Task Force on Transportation Asset Management, which has prepared a Strategic Plan of activities proposed over a 10-year period.

Recently the National Cooperative Highway Research Program (NCHRP) initiated Project 20-24(11), *Asset Management Guidance for Transportation Agencies*. This project, scheduled to be performed in 1999-2002, will develop products that respond to several tasks in the AASHTO Strategic Plan, including a Synthesis of current practice, a Framework of Transportation Asset Management, a recommended program of prioritized research proposals, and an Asset Management Guide. The following discussion of transportation asset management is based upon concurrent work now being conducted for Project 20-24(11).

What Is Asset Management? ***Transportation Asset Management represents a strategic approach to managing transportation infrastructure***. Transportation agencies worldwide have historically exercised significant responsibilities in conceiving, building, operating, and maintaining networks of facilities. Asset management represents more than these combined responsibilities. It entails more than the revision of an internal procedure, preparation of an additional report, or introduction of a new computer application. It embodies an overarching set of principles, best practices, and applications of information to perform management functions better, with the following strategic goals:

- To build, preserve, operate, and reinvest in facilities more cost-effectively with improved performance;
- To deliver to an agency's customers the best value for the public tax dollar spent; and

- To enhance the credibility and accountability of the transportation agency to its authorizing body.

Asset management goes to the core of how an agency does business. The specific nature of the change implied by asset management will vary by agency to conform to local organizational, institutional, financial, managerial, and technological factors. Nonetheless, a set of principles characterizes asset management generally. These principles reflect the concept that transportation asset management is, simultaneously, a philosophy, a process, and a set of technical tools.

Asset Management Is a Philosophy. Asset management represents an approach to managing infrastructure that is strategic and proactive, and places a premium on good information in all aspects and in all departmental units. Relevant principles include the following:

- **Asset management is holistic**. It entails a comprehensive view across a range of assets. It encourages consideration of a full range of options to meet problems or needs. Tradeoffs are explicitly considered among programs, modes, or strategies.

- **Asset management is driven by policy goals and objectives based upon performance**. Strategies are analyzed in terms of objective assessments of costs, benefits, and other impacts on the transportation system and levels of service provided to transportation users.

- **Asset management takes a long-term view of infrastructure performance and cost**. The benefits of different actions are assessed throughout the infrastructure service life, applying economic as well as technical criteria.

- **Asset management is proactive**. An agency has the latitude to make decisions based on merit. Preventive strategies are encouraged where they are cost-effective.

- **Asset management policy is influenced and informed by good information**. This information describes current and projected system condition and performance that

would result from different policies or strategies. It also encompasses user perceptions of system condition and performance, as obtained through surveys or focus groups.

Asset Management Is a Process. Principles of good asset management can suggest ways in which an agency's business processes and its organizational roles and responsibilities can be strengthened. These process improvements can occur in those activities prior to budget approval – i.e., planning and program development – and in the program delivery phase subsequent to budget approval. Major principles governing process improvements are listed below.

- **Investment choices and decisions on allocating and applying resources are policy- and performance-driven**. Procedures to reach these decisions are consistent with objective information and criteria based on merit. Performance measures consistent with policy goals and objectives are established for management review of both system performance and program delivery.

- **Investment choices and decisions on allocating resources are based upon explicit tradeoffs among modes, programs, or strategies**. Tradeoffs assess the impacts of more or less investment in a mode, program, or strategy, and help to craft final recommendations on how resources will be allocated across competing needs. Managers also understand the implicit tradeoffs in their programs and budgets, and the consequences thereof.

- **Organizational roles and responsibilities regarding asset management are developed to overcome silo-based thinking**. While strong vertical organizational units may exist to maintain core expertise, communications and decisions involve wider participation, as noted below.

- **Asset management is interdisciplinary.** Decisions on investment choices and resource allocation are based upon expertise and judgment from several quarters of an agency.

- **Asset management requires effective communication within and outside the agency**. Within the agency, strong communication channels are needed both vertically and

horizontally. External communications need to inform policy makers and other stakeholders of the status of transportation assets and recommended policies and their benefits.

- **The agency strives for more effective program delivery**. The agency explores innovative methods to deliver the range of projects and services required. All available methods are considered, including use of departmental employees, intergovernmental agreements, outsourcing or managed competition, and privatization.

Asset Management Is a Set of Technical Tools. Effective management systems and complete, current, and accurate information on transportation infrastructure are practical necessities in meeting the policy and process requirements of asset management. Good asset management implies a systematic, integrated approach to project selection, analysis of tradeoffs, and program and budget decisions. It also implies that the right information be available to the right levels of management at the right times. The principles below support the availability and application of better information to make better decisions in asset management.

- **Complete, current, and accurate information** on transportation infrastructure assets, including descriptions, location, usage, unique or specialized characteristics, functional and other classification, and data needed for management systems as discussed below.

- **An appropriate suite of management systems and databases** informs the agency of the status, trends, and needs regarding its infrastructure assets. Typical capabilities of these systems include the following:

  – **Organization of information within databases** describing infrastructure inventory, condition, and performance;

  – **Analytic models** that predict the rate of future change in condition or performance, enabling the agency to forecast future infrastructure needs;

  - **Decision rules or procedures** for applying treatments or actions to maintain, rehabilitate, replace, or expand transportation infrastructure, with analytic models of resulting costs, benefits, and other impacts; and
  - **Reports** tailored to different organizational levels of management, including senior and executive levels, as well as for public distribution.

- **Information on system performance** in terms of both proposed targets and values actually achieved in the field. These data may be obtained in a number of ways:
  - Periodic surveys and assessments of system condition or levels of service;
  - Customer surveys of satisfaction with system condition and agency performance; and
  - Incorporation of performance measures and associated backup information within management systems.

- **Specialized technical applications** that support an agency's asset management procedures. These will vary by agency, but may include advances such as use of geographic information systems (GIS) as a system/data integration platform, economic analysis applications (e.g., generalized life-cycle benefit-cost procedure), and decision-support tools.

- **Applications that assist in program and service delivery**, including financial applications (e.g., to compute "total" or "true" cost of agency and contracted services), and management systems for construction project pipeline and construction delivery.

Asset Management Framework – Overall Approach. These principles of good practice are embodied in an approach to asset management that is illustrated in Figure 1. Figure 1 shows a strategic, integrated, systematic, and interdisciplinary approach to asset management, from policy formulation through delivery and monitoring of results. Key points to note are as follows:

- **The approach is policy-driven**. Applicable policies include those embodying system performance goals, and broader policies with important transportation implications, such as those specifying economic development or social or environmental initiatives.

- **The analysis of options and tradeoffs is strategic, interdisciplinary, and integrated**. It encompasses a number of modes and their asset classes, rather than a singular view of any one type of infrastructure. Policy goals and objectives are explicitly considered, with examples in Figure 1 drawn from CDOT's Investment Categories. Different types of investment or expenditure are considered, cutting across programs, to identify the strategy that provides the best performance at the lowest life-cycle cost. Quality information is applied throughout these processes.

- **Decisions on allocating departmental labor, dollar, and information resources among programs are made by managers based upon objective analyses of merit**. These decisions respond to policy goals and objectives, are founded in objective analyses of costs, benefits, and other impacts, and are informed by tradeoff analyses that illustrate the consequences of allocating these resources in different ways.

- **Program projects and services are delivered in the most effective way available**. Options for delivery are continually evaluated in terms of the agency's own capabilities and those of other providers in the public or private sectors.

- **The information base for asset management is continually renewed, with feedback for updates and improvement**. Working upward from the bottom in Figure 1 to consider the several feedback loops possible:

  - **Program delivery monitoring** documents whether projects and services have been delivered on time and budget, and identifies causes of problems that may require remedy;

  - **System performance monitoring** quantifies the results of past investment decisions, establishes baselines for future decisions, and identifies updates needed in project selection criteria;

- **System and customer surveys** update information on current asset inventory, condition, and performance, and the cost and effectiveness of project treatments and service delivery methods for use in future analyses; and
- **System performance monitoring** provides the information basis for future policy formulation and needed updates to goals and objectives.

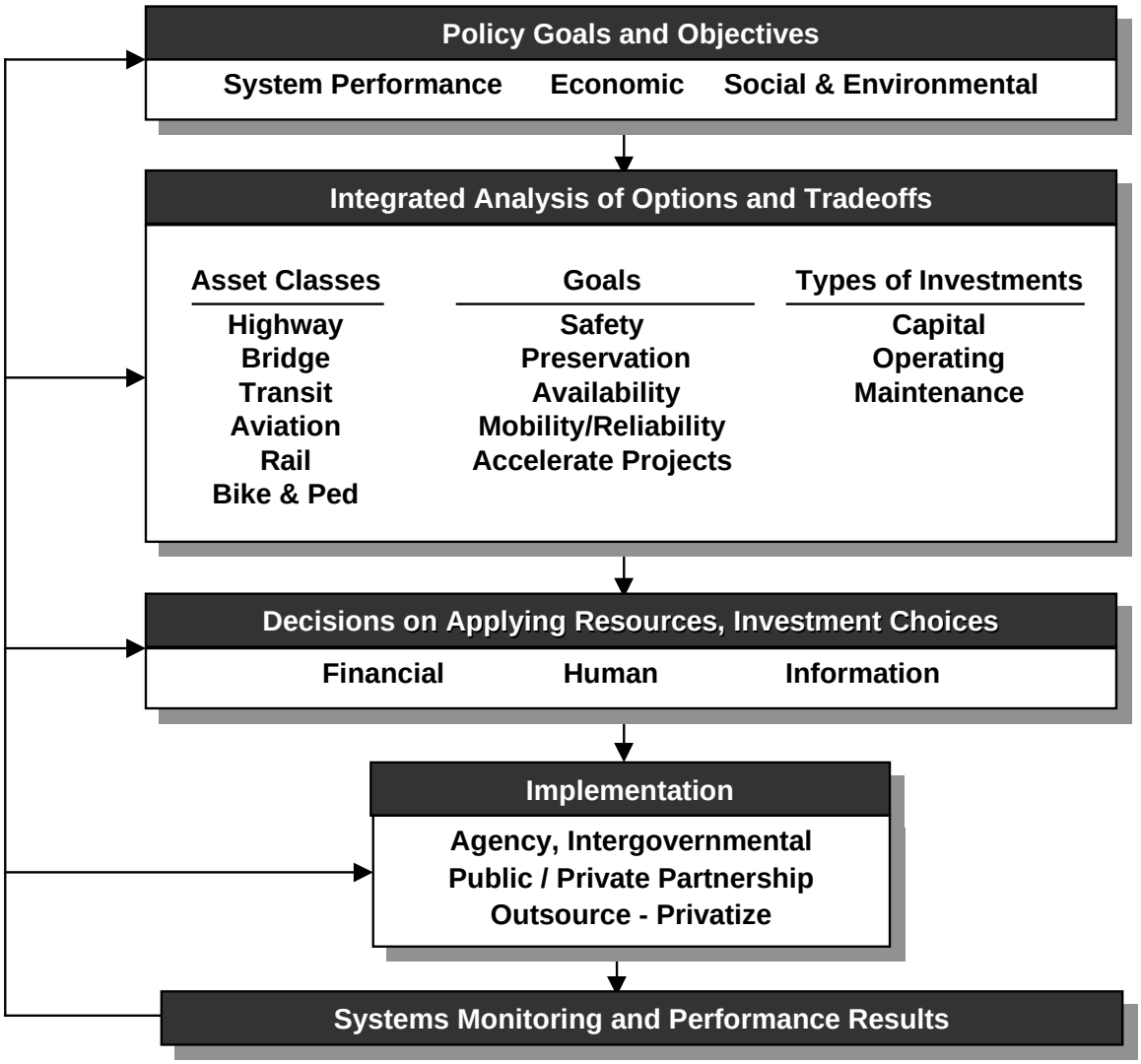

Figure 1. Framework of Transportation Asset Management

Implications for This Study. Asset management is a comprehensive undertaking within an agency, since it goes to several business processes and decision points regarding a significant component of a transportation department's program budget. Moreover,

proposals for asset management improvement must be tailored to the particular policies, management philosophies, transportation network characteristics, and organizational, financial, institutional, and technological constraints that affect an agency's decisions and actions. An illustration of key areas in which asset management can affect an agency's activities organizationally is shown schematically in Figure 2.

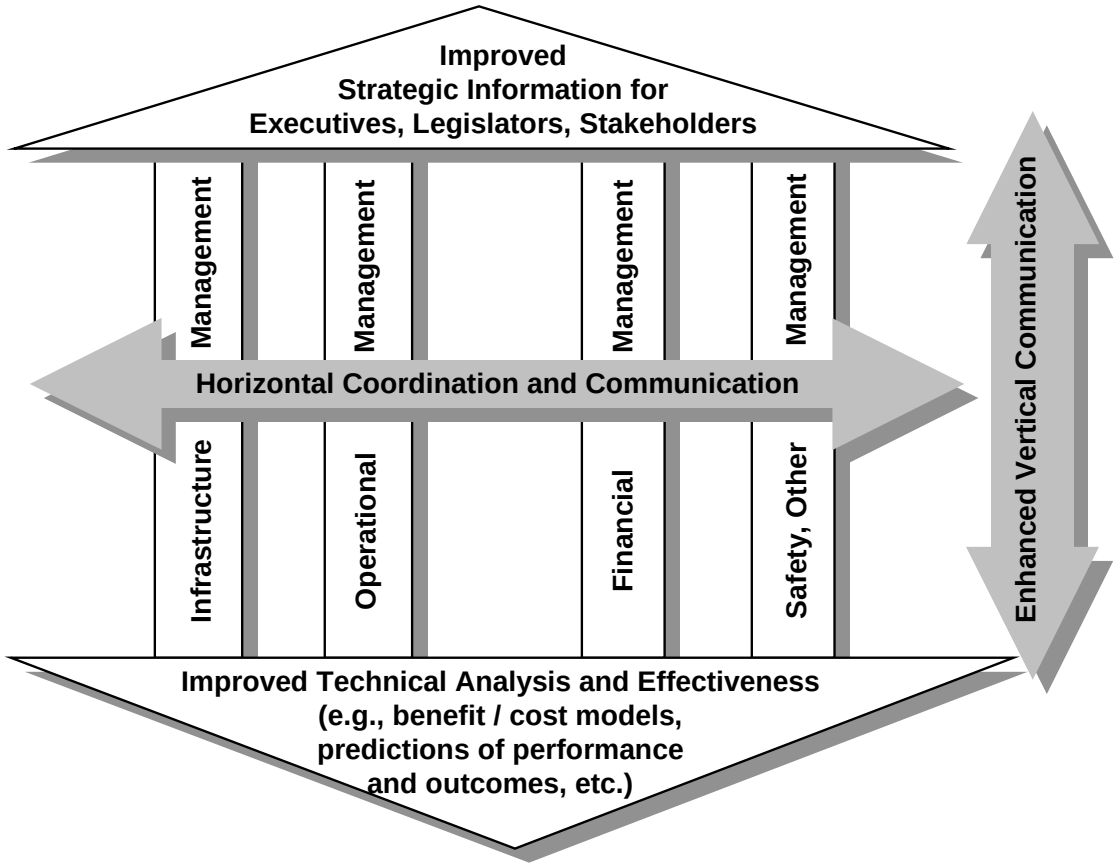

Figure 2. Implications of Asset Management for Agency Processes and Information Flows

Vertical elements in the center of Figure 2 signify core competencies within an organization. For simplicity, only four such groupings of expertise are shown, corresponding to infrastructure management, operations management, financial management, and safety and other areas of management. In fact, each of these may encompass several distinct subareas: e.g., infrastructure management may include skills in design, construction, pavement management, bridge management, traffic management,

track engineering and management, as well as modal specialties. From a practical perspective, core competencies such as these will likely continue within an agency, whether located in central offices, district or regional offices, or in some partnership arrangement with the private sector. The goal of asset management, however, is to ensure that these competencies are applied within an integrated, interdisciplinary environment, and that they not be isolated "with blinders on" in a "silo" or "stovepipe" approach to problems.

Asset management seeks to strengthen organizational processes and decisions across these core competencies. Improved processes, management systems, and analytic tools are a key element of asset management, as discussed earlier. Within middle management and at technical departmental levels these improvements may be visualized as new procedures, techniques, and skills that improve effectiveness, complemented by improved analytic tools and applications (whether stand-alone or within existing management systems), as shown at the bottom of Figure 2. At executive levels of the organization the focus is on the availability of improved information for decision-making and for communicating to governing bodies, customers, and other stakeholders, as shown at the top of Figure 2. Achieving a department-wide understanding of asset management and enabling the interdisciplinary approaches needed requires strengthened communication – vertically within core competencies and to executive levels, and horizontally across the department's organizational units and disciplines, as depicted prominently in Figure 2. Collectively, this set of improvements enables the agency to establish and sustain a philosophy of asset management in a practical and meaningful way.

The remainder of this report illustrates how these concepts of asset management can be applied within Colorado DOT to develop a plan for asset management improvement.

2.0 State-of-Practice at CDOT

2.1 Departmental Overview

Transportation in Colorado. Colorado's transportation needs are shaped by many factors of geography, economy, and society. Colorado occupies a strategic location in the Western United States, astride major east-west and north-south continental land and air routes. Variations in terrain, climate, and demographic characteristics contribute to a diverse economic base encompassing the agricultural and growing service sector in the Eastern Plains, rapidly growing suburban areas and economic transformations in the Front Range, and the Western Slope with its ranchlands and tourist attractions superimposed upon largely rural areas.

These characteristics, which contribute to the economic vitality and appeal of living in or visiting Colorado, also create challenges in meeting the state's transportation needs. In providing statewide transportation services, CDOT must strike a balance in meeting local, interregional, interstate, and international-bound demands for moving passengers, freight, and information, while addressing both urban and rural interests among its citizenry. Statewide goals to which transportation contributes in a critical way – e.g., to accommodate rapid growth, sustain a healthy economy, preserve the natural, scenic beauty and environmentally sensitive areas of the state, respond to transportation needs among different population groups, and deliver transportation services cost-effectively even under conditions of high altitude and difficult weather – must be accounted for in CDOT's decisions on the allocation of resources among competing transportation investments and services.

The remaining parts of this section will describe CDOT's organizational structure and policy framework, processes for planning and program development, and information resources that define the procedural approach and culture for these decisions, and the implications for transportation asset management.

CDOT Organization. The organizational structure of CDOT is depicted in Figure 3.

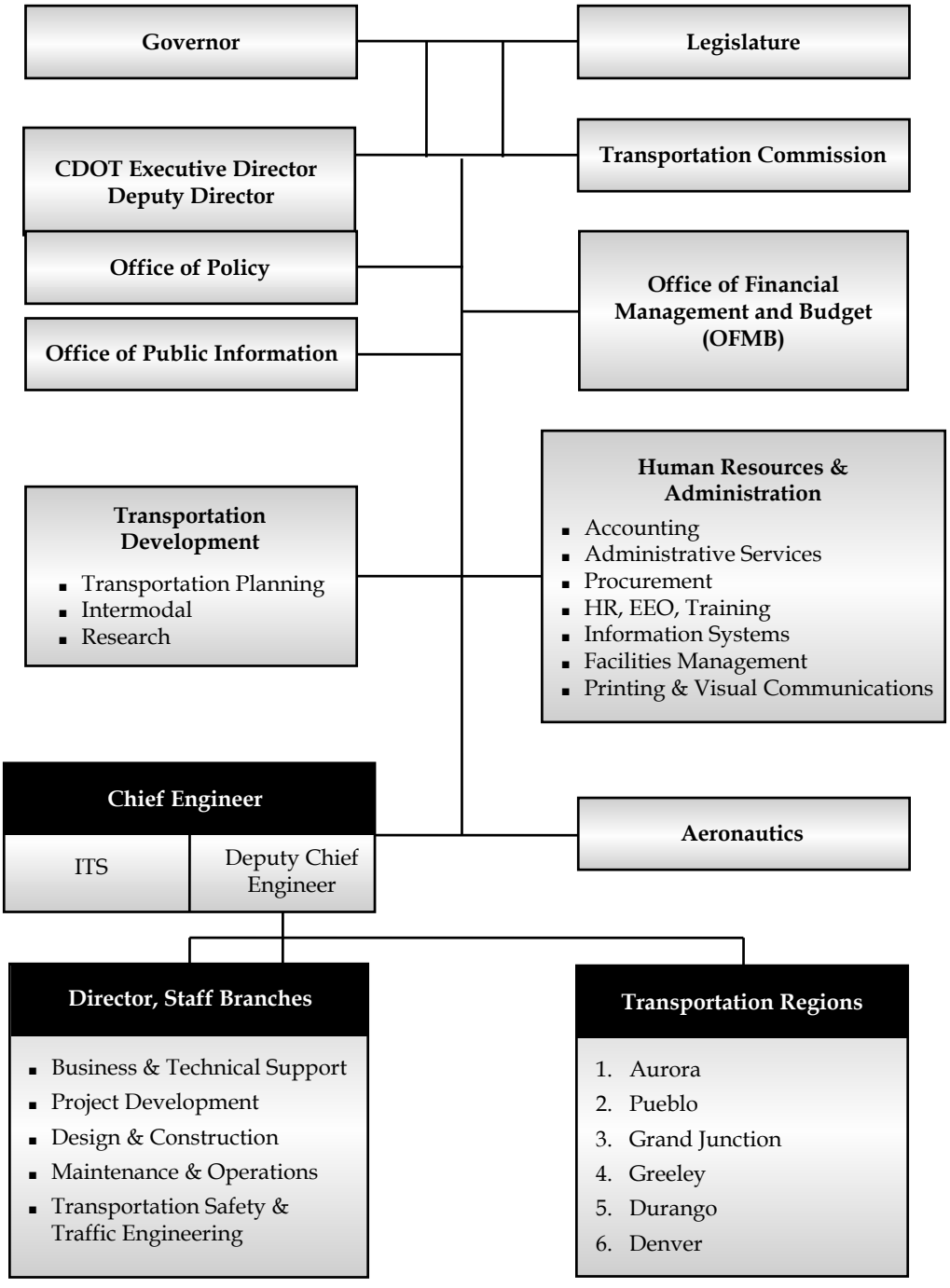

Figure 3. CDOT Organizational Structure

- The **Executive Director** provides overall direction and management of the Department. He or she is assisted by the **Deputy Director**.

- Assisting and reporting to the **Executive Director** and the **Deputy Director** are the Directors of the following offices: **Policy** (responsible for political liaison and policy analysis support), **Financial Management and Budget (OFMB)**, and **Public Information**.

- Also reporting to the Executive Director and the Deputy Director are the heads of four CDOT **divisions**:

  - **Division of Engineering & Maintenance**, headed by the Chief Engineer. This division is responsible for engineering services provided by the central and the Regional offices, as explained further below.

  - **Division of Transportation Development (DTD)**, headed by a Director responsible for transportation planning, promotion of intermodal transportation, Departmental conformity with the Clean Air Act, collection of federally required traffic and road inventory data, and research.

  - **Division of Aeronautics**, headed by a Director responsible for administering Aviation Fund revenue, assisting with Federal Aviation grants, providing technical and administrative assistance to Colorado's Aeronautical Board, and facilitating refunds of taxes to governmental units operating public-use airports.

  - **Division of Human Resources and Administration**, headed by a Director responsible for employee services, equal opportunity, procurement, information systems, accounting, facilities management, training, and printing and visual communications.

- The **Division of Engineering & Maintenance** encompasses a number of functions and services:

  - The **Director, Staff Branches**, oversees CDOT central office branches that provide technical expertise and program guidance in roadway and bridge design, construction,

maintenance and operations, safety, right-of-way, environmental services, and materials testing.

- The **Chief Engineer** and his/her deputy oversee the activities of the Staff Branches and the construction and maintenance activities in Colorado's six transportation Regions (discussed below).
- The **Intelligent Transportation Systems (ITS) Program** oversees departmental implementation of ITS technology.

- CDOT delivery of projects and services and liaison with regional planning bodies and other local constituencies is handled organizationally through six CDOT **Transportation Regions**, as shown in Figure 4. Each Region is headed by a Regional Transportation Director (RTD), who oversees assigned engineering and maintenance/operations staffs.

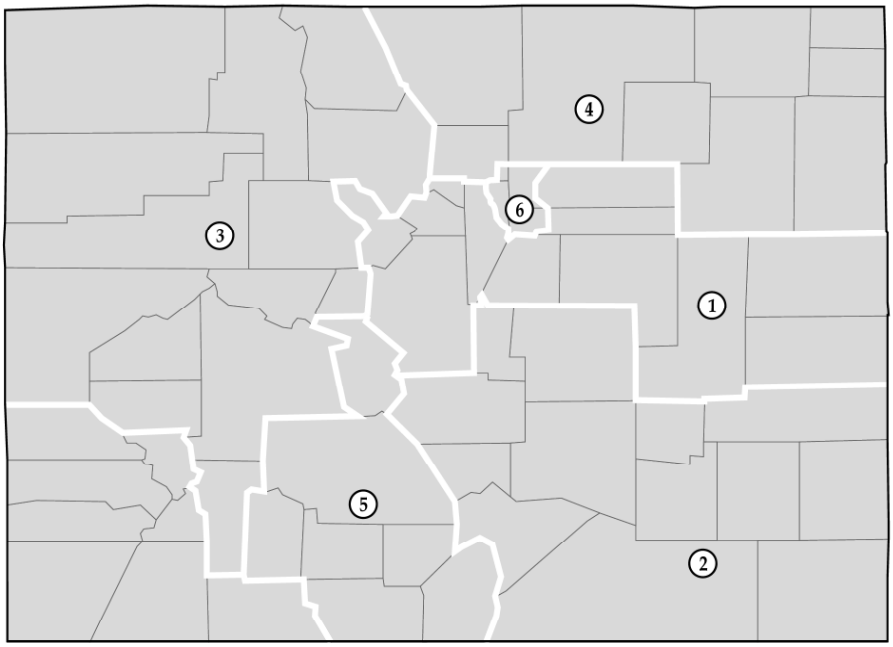

Figure 4. CDOT Transportation Regions

- CDOT maintenance forces within each Region are organized within **maintenance sections** that are part of the Regional organization, as shown in Figure 5.

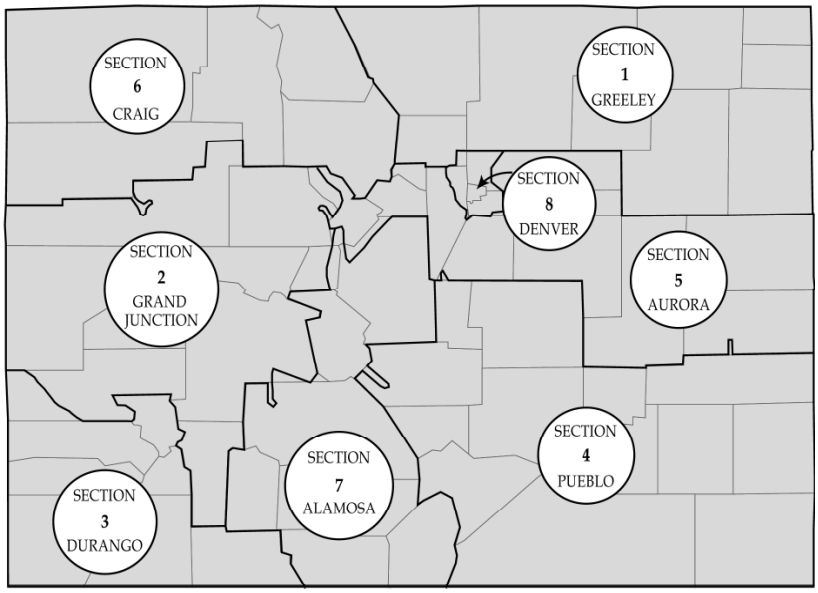

Figure 5. CDOT Maintenance Sections

Transportation Commission. The Transportation Commission formulates policy and provides guidance to CDOT regarding the construction, maintenance, and management of state highways and transportation systems. The Transportation Commission comprises 11 members who are appointed by the Governor and confirmed by the Senate for staggered four-year terms. Each commissioner represents one of the 11 districts shown in Figure 6.

The role of the Transportation Commission in establishing transportation policy and providing overall guidance is exercised in a number of ways. The Transportation Commission meets monthly with CDOT executives and managers to review program status, provide overall program direction and priorities, and adopt CDOT programs and budgets. Policy directives and guidance are issued from time to time, and examples will be given shortly. The Transportation Commission also advises the Governor and the General Assembly on transportation policy.

At a strategic level, the Commission meets with CDOT executives at two- to three-year intervals to review systematically the 20-year planned allocation of resources among programs, to re-examine and update policies and program priorities, and to explore tradeoffs in proposed funding among programs. Descriptions of the structure and

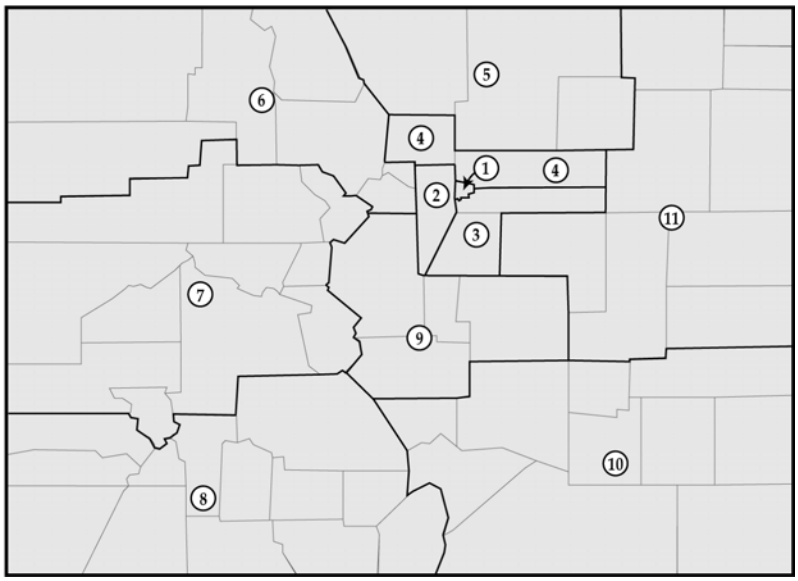

Figure 6. Transportation Commission Districts

composition of CDOT transportation programs that define the potential options that can be considered in these tradeoffs are given in later sections.

Statewide Transportation Assets. CDOT now manages programs and pass-through funding that encompass a number of transportation assets: roads and bridges, transit and rail track and facilities, airports, and bicycle and pedestrian ways. These assets are reviewed below in terms of Transportation Commission policies and CDOT responsibilities to identify the scope and focus of the transportation assets that are addressed in this report.

- **State highways** constitute the primary state-owned transportation assets under the jurisdiction of CDOT, as discussed in Section 1.0.

- The Transportation Commission has identified criteria for determining **State Significant Rail Corridors**. It has also formulated a Rail Corridor Preservation Policy that could result in CDOT "ownership" of either abandoned rail lines or rights-of-way for proposed new rail lines to mitigate abandonment of existing service or to preserve future transportation options in an existing corridor. This policy currently results in CDOT ownership of one rail line, which is now leased to an operating company.

- **Transit services** in Colorado are provided by local or regional operators to meet the needs of the general public in urban, rural, intercity, and resort areas/routes, and to provide specialized services for elderly and disabled riders. CDOT does not provide any state funds for transit, but administers federal funds to transit operators serving rural areas and elderly and disadvantaged populations. In the context of Section 1.0, transit overall is a mode of "state interest" to CDOT.

- The Transportation Commission and CDOT view **bicycle and pedestrian ways** as integral components of the state's multimodal transportation system. Routes designated by the Transportation Commission as High-Priority Bicycle Corridors provide a focus for CDOT funding of shoulder improvements or resurfacing when highway/bridge construction, rehabilitation, or widening projects are scoped. Bicycle and pedestrian projects may also be included in Regional Priorities funded by CDOT.

- Colorado's **commercial and general aviation airports** are owned and operated by local governments, with funding assistance from both federal (Federal Aviation Administration, or FAA) and state (Colorado Aeronautical Board) grants. Airports are of state-interest to CDOT given the importance of air transportation to the local economy, mobility, and accessibility of locations throughout the state. CDOT provides technical and planning assistance to the Aeronautical Board and local and regional agencies regarding airport needs.

- Movement of information within a multimodal context is interpreted by the Transportation Commission to apply specifically to **Intelligent Transportation Systems** (ITS) technology and to modern communications and information linkages among CDOT buildings and operations centers.

The focus of this report is primarily on the state highway assets for which CDOT has ownership and operating responsibility and which represent significant shares of CDOT programs and budgets. Investments and service improvements in the highway network are assumed to include associated improvements in pedestrian and bicycle facilities or ITS devices where appropriate, as well as rail corridor preservation actions that may relate to a

highway corridor. Asset management decisions affecting highways will also affect the quality of transit service that can be provided by transit operators, and the accessibility of aviation facilities to passenger and freight motorists.

2.2 Transportation Policies and Program Structure

CDOT Mission and Statewide Transportation Policies. The Colorado Transportation Commission from time to time issues policy directives to guide CDOT program decisions and priorities and to articulate the underlying values that CDOT stands for and pursues in its daily work. Policy Directive 14, adopted in 1996, defines CDOT's mission "to provide the best multimodal transportation system for Colorado that most effectively moves people, goods, and information." Policy directive 14 also enumerates a set of values to guide CDOT in fulfilling its mission: e.g., to provide leadership in transportation while working in partnership with others, to strive for quality while taking pride in self and in work and seeking to improve personal skills and talents, to use resources wisely, and to make decisions that are compatible with Colorado's quality-of-life, environmental, and economic goals.

These value statements reiterate many key precepts of the comprehensive Statewide Transportation Policies that were adopted by the Transportation Commission in Policy Directive 13 (1994). The essential principles of these statewide policies are summarized below:

- **Customer Focus –** Strengthen outreach and communication to the public, and solicit and respond to views of those affected by transportation performance, improvements, and financing;

- **Leadership –** Bring together varied interests, and apply CDOT's statewide perspective and expertise to reach optimal transportation solutions together;

- **Management of the Transportation System –** Facilitate the efficient movement of people, goods, information, and services through a unified transportation system, considering the full range of alternatives to meeting customer needs;

- **Intermodalism –** Develop a balanced transportation system that meets the needs of diverse sets of customers by taking advantage of the efficiencies of appropriate modes, and by ensuring connectivity and interaction among these modes;

- **Partnership –** Form partnerships (both formal and informal) to leverage CDOT's limited resources and to tap new sources of support for transportation development;

- **Integrate Regional and Statewide Priorities –** Collaborate with partners to integrate local, regional, and statewide transportation priorities;

- **Finance –** Pursue diverse, cooperative funding mechanisms that are reliable, equitable, flexible, adequate, and acceptable; enhance financial management to provide cost accountability for achieving target benchmarks;

- **Safety –** Promote transportation safety to road users and workers through education, engineering, and enforcement;

- **Balance Quality of Life Factors –** Work with local, regional, and state interests to balance the long-range transportation, land use, and quality of life needs in meeting objectives of mobility, economic vitality, and environmental preservation;

- **Environment –** Promote a transportation system that is environmentally responsible in its planning, design, construction, maintenance, and operation; consider all reasonable alternatives to avoid or minimize adverse effects;

- **Accessibility –** Promote a transportation system that is accessible to users, including the transportation disadvantaged; accessibility encompasses choice of modes, good connections, ease of use, relative cost, and proximity and frequency of service; and

- **Social Responsibility –** Provide a safe, healthy, nondiscriminatory work environment for employees; follow fair business practices; keep the public welfare continually in mind in making decisions.

Many of these policy statements echo themes that are also identified with principles of good asset management. The issue in outlining an asset management plan then becomes one of how these policies are translated into specific program elements and procedures used by CDOT.

To develop this information, we first summarize below the categories of existing transportation programs managed by CDOT, their objectives, and relative priority. Commission policies and guidelines regarding these programs will also be discussed, since collectively these define key elements of CDOT's existing decision-making culture regarding transportation asset management.

A unique approach pioneered by CDOT has been to define "Investment Categories" that impose a policy- and performance-oriented view of transportation programs, and that enable the Department to analyze cross-program tradeoffs serving a particular objective. Discussion of these program elements is followed by overviews of the CDOT planning and program development processes, mechanisms and management of program delivery, and decision support provided by management systems and related databases.

Statewide Programs. State and federal funds are distributed among several programs managed by CDOT that address statewide transportation needs. These funded statewide programs are listed in Table A, identifying for each program the scope of work, applicable program goals or targets, and remarks on sunset provisions or plans for further development of program elements such as analytic models. The nature of program goals or targets is identified where applicable as performance-based (i.e., reflected in a measurable characteristic of the transportation system), financial (i.e., based upon an annual expenditure level approved by the Transportation Commission and reflected in Colorado's Statewide Transportation Plan), or both. Certain programs respond to specific requirements of the federal Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 or the

Transportation Equity Act for the 21st Century (TEA-21) of 1998, as noted. Management system support of program performance measures and project selection decisions are identified regarding CDOT's pavement management system (PMS) and Pontis® bridge management system (BMS).

Table A. Funded Statewide Programs

Program Title and Scope	Goals or Targets, Other Remarks
Strategic Transportation Investment Program ("7th Pot") 28 long-term, high-priority transportation projects	Strategic projects selected by Transportation Commission for accelerated funding and completion
Surface Treatment Program Resurfacing and rehabilitation of state highway pavements	Performance-based goal of at least 60 percent of pavements statewide in good or fair condition; individual condition targets defined by highway system; performance-based project selection based on PMS estimates of remaining service life
Bridge Program Bridge rehabilitation or replacement to address structural and functional deficiencies	Financial targets established for rehabilitation and replacement of on-system bridges and inspection of on- and off-system bridges; future enhancements to Pontis® BMS models/usage will allow performance-based goals in terms of structural and functional sufficiency related to funding needs; performance-based project selection assisted by Pontis® BMS
Rest Area Program Rehabilitation, reconstruction, or relocation of existing rest areas	Financial targets established for work on priority rest areas; program to sunset in FY 2004 when completed
Noise Barrier Program Installation of noise barriers to address significant noise impacts on federal highways	Financial targets established for identified locations; due to sunset in FY 2002 when completed

Table A. Funded Statewide Programs (continued)

Program Title and Scope	Goals or Targets, Other Remarks
Small Urban Program Funding for Small Urban Areas to fulfill Transportation Improvement Program (TIP) commitments	Transition program to cushion impact of ISTEA's elimination of Federal Aid Urban System (FAUS) funding; financial targets established and distributed by population-based formula; program to sunset in 2004
Safety Program Highway feature improvements and driver behavior and enforcement programs to reduce accident rates and increase seat belt use	Performance-based reduction in motor vehicle crashes, injuries, and fatalities on the state highway system tied to financial targets
Maintenance Program Maintenance services for roadways, bridges, roadsides, tunnels, snow and ice control, traffic appurtenances, rest areas	Performance-based target levels of service set by Transportation Commission corresponding to projected facility condition and degree of response to storms or incidents
Operations Program CDOT administrative and engineering operations: e.g., administration, aeronautics, program support, transit support, workers compensation insurance, gaming funds, CDOT equipment and property, engineering program, etc.	Funding levels set by Transportation Commission to deliver programs, maintain CDOT facilities, etc.
Intelligent Transportation Systems (ITS) Installation, integration, and maintenance of ITS technology, including the Traffic Operations Center and the Colorado Transportation Management System	Financial targets established and tied to priority projects/locations.

The Strategic Transportation Investment Program is listed first in Table A. This program addresses projects of significant, long-term importance in which major mobility, safety, or

system quality improvements have been given high priority by the Transportation Commission. As this program is given high priority in the allocation of statewide funds, it is sometimes identified separately from the other funded statewide programs.

Regional Programs. CDOT works cooperatively with Colorado's 15 Transportation Planning Regions (TPRs, Figure 7) to develop regional programs that meet statewide and regional mobility, safety, and environmental needs. Funds available for regional programs are determined after statewide funding needs have been met. Regional programs are organized in the following categories:

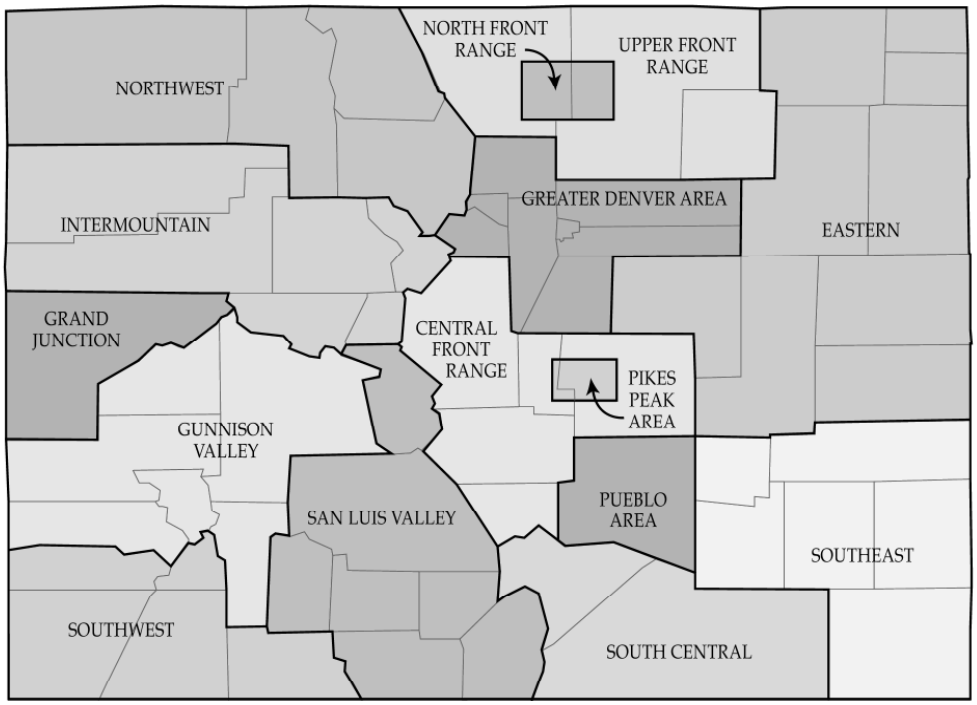

Figure 7. Colorado Transportation Planning Regions

- **CMAQ –** The Congestion Mitigation and Air Quality (CMAQ) Improvement Program is a federal program that directs funds to transportation projects in Clean Air Act non-attainment areas for ozone and carbon monoxide. Federal funds are distributed on the basis of each state's share of the population in non-attainment areas, weighted by degree of air pollution. Within Colorado the funds are distributed based upon the respective

Metropolitan Planning Organization (MPO) Air Quality Conformity Plans, plus funding to mitigate particulate (PM_{10}) non-attainment in several rural areas.

- **STP –** Federal Surface Transportation Program (STP) funds are distributed by federal formula among several objectives:
  - 10 percent set-aside for Safety and 10 percent set-aside for Enhancements;
  - A division of 50 percent of the funds between the state's Transportation Management Areas (TMAs: urbanized areas with population greater than 200,000)[1] and other areas of the state, in proportion to the relative share of the state's population in each of these two groups; and
  - The remaining 30 percent for use in any area of the state.
- **STP Enhancements –** Enhancements encompass a number of improvements including pedestrian and bicycle facilities, scenic or historic projects, landscaping and beautification, preservation of abandoned rail corridors, archaeological planning and research, and mitigation of water pollution due to highway runoff. Federal funding is 10 percent of STP funds, as noted above. Distribution within CDOT to Regions is by formula[2]; the Regional Transportation Director works with local entities to determine specific project selection and funding levels.
- **Other Regional Construction Priorities –** This program encompasses primarily mobility and safety improvements accomplished through reconstruction, restoration, and rehabilitation; major and minor highway widening; new construction; roadway and operational improvements; and transportation safety management. The distribution of funds among Regions applies the same formula as that used for Enhancements.

[1] The TMAs in Colorado include Denver and Colorado Springs.

[2] The weighted formula is as follows: 45 percent based on vehicle miles of travel (VMT), 40 percent based on lane miles, and 15 percent based on truck miles of travel.

Transportation Commission Guidance. In addition to broad statewide transportation policy statements such as those cited earlier, the Transportation Commission provides more specific policy direction and guidance on particular transportation programs and initiatives. These guidelines in particular strongly influence the "culture" at CDOT regarding asset management decisions in terms of overall philosophy and options that may realistically be considered. Current guidance includes the following items excerpted from ***The 2020 Statewide Transportation Plan: Investing in Colorado's Future***, which have been grouped informally under the indicated headings:

Classifying and Planning the Transportation System

- The Transportation Commission recognizes the value of a tiered transportation system to aid in optimizing investment and supports the development of performance objectives appropriate to the role facilities play in the transportation system.

- Planning procedures to investigate alternatives for corridor improvements should be updated to ensure that the most efficient use is made of available resources and opportunities in the corridor planning process.

- The role of the Transportation Commission in corridor planning should be clarified: Any corridor study affecting the state highway system should receive Commission approval prior to implementation, to improve coordination of planned actions.

- Given current resources, the Transportation Commission will continue its high priority on preservation, enhancement, and maintenance of the existing infrastructure. However, the Commission recognizes that judicious expansion of the state transportation system may be necessary to respond to projected growth. Expansion may include increases in current corridor capacity, addition of new corridors, or redesignation of local roads. Additions to the state system must be consistent with the role and function of the state highway system and are contingent upon availability of funds, an exchange of facilities with local governments, or partnerships with public and private entities.

- The Commission has directed that a high tier of priority bicycle corridors be identified to potentially help focus limited resources to those facilities with the greatest need and benefit.

Modal Flexibility

- The Transportation Commission recognizes the role of alternative modes in addressing mobility needs, and it supports using federal and Senate Bill 99-1 funding flexibility for strategic projects. The Transportation Commission supports modal flexibility for existing and new transportation revenues within constitutional, legislative, and regulatory constraints and the Commission's program priorities.

- The Transportation Commission recognizes and will support the various roles of CDOT's planning partners and of transportation providers in coordinating an integrated, intermodal transportation system for Colorado.

- Recognizing the importance of transit as an integral part of Colorado's transportation system, the Transportation Commission supports the development of new funding sources to supplement local transit capital needs and to fund intermodal projects that benefit the state's transportation system.

- The Commission supports using Other Regional Priority funds for alternative mode projects that benefit the state's highway system and that are prioritized through the regional planning process.

Environmental Policy Guidance

- The Transportation Commission supports proactive techniques that mitigate transportation system impacts on the environment by developing strategies that:

- Comprehensively address the anticipated environmental impacts of the state transportation system;
- Consider project enhancements in affected communities in a cost-effective manner that is consistent with the mission of CDOT; and
- Expedite project development.

Relationship to Off-System Facilities

- The Commission recognizes the significant demands placed on local governments to provide and maintain municipal and county roads and bridges. It supports continued sharing, as prescribed by existing formula, of the Highway User Tax Fund (HUTF) and any increases to the HUTF. In addition, the Commission supports sharing new sources of voter-approved statewide transportation revenues with local governments.

Telecommunications Policy

- Recognizing both the potential importance of telecommunications to the state's transportation system in the future and the paramount role of the private sector in its development, the Transportation Commission takes the following positions:
  - It does not intend to compete with private industry in providing telecommunications services to the public;
  - CDOT telecommunications activities will accordingly be limited to the deployment of Intelligent Transportation System (ITS) projects and programs, and in partnership with the private sector, providing telecommunications infrastructure to CDOT facilities statewide; and
  - Regarding the role of ITS in the regional and statewide planning process, the MPOs and Regional Planning Commissions (RPCs) are encouraged to consider ITS projects within their regional transportation plans. Transportation-related ITS projects are eligible to compete for Other Regional Priority funds. The Commission supports

commitment to coordination and planning among the state, local governments, and private providers.

Investment Categories. Program Investment Categories enable CDOT and the Transportation Commission to relate statewide programs to explicit policy goals and objectives, monitor progress and provide accountability through defined performance measures, and structure tradeoffs among programs to evaluate investment choices and their impacts on system performance and customer satisfaction. While other DOTs in the U.S. have likewise created policy-responsive and performance-based approaches to planning and programming, the CDOT approach is unique in that Investment Categories encompass all statewide transportation programs – maintenance and operating as well as capital. The definition of elements (such as performance measures) for the Investment Categories is still evolving. Nonetheless, the Investment Categories have already provided a useful framework for planning, programming, and resource allocation decisions by the Transportation Commission and CDOT, and the Investment Category structure will help frame several of the CDOT activities in transportation asset management recommended later in this report.

Five Investment Categories have been defined in the CDOT approach: Mobility, System Quality, Safety, Strategic Projects, and Program Delivery. Key elements of each are described in the following sections.[3]

[3] The information on CDOT Investment Categories is based upon the following CDOT sources:
The 2020 Statewide Transportation Plan: Investing in Colorado's Future (DRAFT), July 5, 2000;
Preliminary Performance Report, December 1999;
Strategic Plan and Budget for Fiscal Year 2000-01, April 20, 2000;
Presentation of the Department-wide Objectives, prepared for CDOT and the Transportation Commission by Arthur Andersen, June 21, 2000;
CDOT System Quality Investment Category, prepared for CDOT DTD by In Motion, Inc. and Cambridge Systematics, Inc., January 15, 1999.

Mobility Investment Category

- **Goals**
  - Improve mobility
  - Increase travel reliability

- **Objectives**
  - Seek external customer feedback to improve functional and regional delivery of services
  - Preserve transportation choices as a part of an integrated statewide transportation planning process
  - Maximize efficiency of the existing infrastructure prior to adding new capacity
  - Ensure environmental stewardship of the transportation system
  - Implement transportation improvements that enhance the quality of life and promote community values

- **Program Components within Mobility Category**
  - Highway Performance
  - Alternate Modes
  - Travel Demand Management
  - Facility Management
  - Weather Response
  - Transit: Pass-through of FTA funds to transit agencies

- **Current Mobility Performance Measures**
  - Roadway Congestion Index and newer Travel Rate Index
  - Number of road closures by closure type
  - Duration of road closures by closure type
  - Customer perception of travel time variability

- **Other Possible Mobility Performance Measures**
  - Congested person-miles traveled
  - Congested freight ton-miles traveled
  - Percent of travel needs met
  - Rate of growth in motor vehicle emissions
  - Rate of growth in annual vehicle miles of travel (VMT)

System Quality Investment Category

- **Goals**
  - Preserve the transportation system
  - Keep the system available and safe for travel

- **Objectives**
  - Enhance and maintain the transportation system to ensure maximum useful life
  - Preserve and maintain the existing system prior to long-term construction investments
  - Develop a "travel friendly" transportation system that incorporates customer desires
  - Ensure that investments into the transportation system sustain and/or improve quality of life

- **Program Components within System Quality Category**
  - Pavement
  - Bridge
  - Roadside Facilities
  - Roadside Appearance
  - Rest Areas
  - Traffic Operations Devices
  - Major Tunnels
  - Other Transportation Modes

- **Current System Quality Performance Measures**
  - Pavement surface condition rating of fair or better
  - Bridge sufficiency rating of fair or better
  - Bridge needs versus programmed work, by on-system and off-system bridges
  - Maintenance condition survey (current level of service) for preservation activities

- **Other Possible System Quality Performance Measures**
  - Return on investment for quality-of-life sites

Safety Investment Category

- **Goal**
  - Reduce transportation-related crashes, injuries, and fatalities, and the associated loss to society

- **Objectives**
  - Reduce the rate and severity of transportation-related incidents
  - Promote the education and awareness of safe driving behavior
  - Emphasize applicable safety features consistent with population growth

- **Program Components within Safety Category**
  - Safe Driving Behavior
  - Roadway Safety Characteristics

- **Current Safety Performance Measures**
  - (Reductions in) statewide fatal crash rate, statewide injury crash rate, and statewide total crash rate
  - Customer perceptions of CDOT's safety activities

- **Other Possible Safety Performance Measures**
  - Alcohol-related incidents compared to statewide incident rate
  - Incidents involving seatbelt usage compared to statewide incident rate

- Return on investment for designated improvement sites
- Corridor safety assessment

Strategic Projects Investment Category

- **Goals**
  - Accelerate the completion of the projects
  - Increase investment in the program

- **Objectives**
  - Promote partnerships with all governments to enhance working relationships
  - Accelerate strategic project delivery while minimizing the impact to all other objectives
  - Prepare transportation needs for Colorado's future: Preserve options to anticipate Colorado's future transportation needs in major mobility corridors
  - Ensure CDOT's bonding eligibility to secure future funding levels

- **Program Components within Strategic Projects Category**
  - Currently 28 strategic project corridors
  - Additional strategic projects now being contemplated

- **Current Strategic Project Performance Measures**
  - Funds budgeted, encumbered, and expended for each project
  - Estimated completion dates and status of each project

- **Other Possible Strategic Project Performance Measures**
  - Percent advertisement ("ad") dates met on-time, within 30 days, 60 days, or beyond 60 days
  - Days to complete payment processing and billing compared to indenture and continuing disclosure

Program Delivery Investment Category

- **Goals**
  - Deliver high-quality products and services in a timely fashion
  - Attract and retain an effective and qualified workforce
  - Foster an environment that respects workforce diversity

- **Objectives**
  - Maintain fiscal integrity to CDOT through timely encumbrance of funds and project delivery
  - Create a funding environment that preserves the base while pursuing new sources
  - Ensure timely product and service delivery
  - Identify innovative human resource solutions that maximize existing resources to meet business needs
  - Create public confidence in departmental accountability
  - Incorporate education in project development and implementation
  - Develop planning processes that enhance future project development
  - Maintain a viable service industry to create a competitive environment

- **Program Components within Program Delivery Category**
  - **Strategic Support –** functions that set, advocate, and communicate strategic direction – e.g., Policy Analysis, Public Relations
  - **General Support –** functions required to support day-to-day operations – e.g., Information Systems, Administrative Services, Procurement, Human Resources, and Financial Management and Budget
  - **Program Support –** functions that are unique to the business of a public department of transportation – e.g., Transportation Development, Right-of-Way services, Environmental Review, and Project Development
  - **Facilities and Equipment –** functions associated with the maintenance, operation, replacement, or upgrading of CDOT's buildings, vehicles, and other equipment
  - **Data Collection –** functions associated with CDOT's data collection programs

- **Program Delivery Performance Measures**
  - None defined at Investment Category level
  - Performance measures defined at Program Level (i.e., for individual Program Components above)

Relating Programs to Investment Categories. The Investment Category structure provides a framework for organizing the statewide and regional programs with respect to their policy goals, objectives, and performance measures. While this relationship in many cases is straightforward, for programs like Highway Maintenance the relationship is complicated by the diversity of maintenance activities and the resulting applicability of the Maintenance Program to several Investment Categories. To illustrate the relationship between funded programs and Investment Categories, consider the System Quality Investment Category and its several Program Components or Areas. The constituent funded programs in each Program Component are listed as bullet items.

Statewide Programs in System Quality Investment Category

- **Pavement Program Component**
  - Surface Treatment Program
  - Portions of **Roadway Reconstruction Program** involving rebuilding of roadway and base
  - **Maintenance Program**, Surface Maintenance (Activity Series 150)

- **Bridge Program Component**
  - **Bridge Program**
  - **Maintenance Program**, Structures Maintenance (Activity Series 350)

- **Roadside Facilities Program Component**
  - **Noise Barrier Program**
  - **Maintenance Program**, Roadside Facilities (Activity Series 200)
  - **Maintenance Program**, Minor Tunnels (Activity Series 500, excluding Eisenhower-Johnson and Hanging Lake Tunnels)

- **Roadside Appearance**
  - **Maintenance Program**, Roadside Facilities (Activity Series 250)

- **Rest Areas**
  - **Rest Area Program**
  - **Maintenance Program**, Rest Area Buildings (Activity 461), and that portion of maintenance activities for roadway surface, roadside facilities, and roadside appearance performed in rest areas

- **Traffic Operations Devices**
  - **Maintenance Program**, Traffic Services (Activity Series 300)
  - **Operations Program/Engineering**, that portion devoted to Region Traffic Engineering and Traffic Operations Centers

- **Major Tunnels**
  - **Maintenance Program**, Tunnel Maintenance (Activity Series 500), that portion devoted to Eisenhower-Johnson and Hanging Lake Tunnels

- **Other Transportation Modes**
  - **Aviation Pavement Program**

A program like Maintenance has work that is distributed not only among several Program Components of System Quality, but also among other Investment Categories – Mobility, Safety, and Program Delivery. Explicit definition of these relationships maintains the financial and programmatic integrity of the Investment Category approach. It also makes possible the definition of appropriate performance measures at each level of the Investment Category structure:

- Investment-level performance measures defined for the entire Investment Category;
- Program-level performance measures defined for each Program Component within the Investment Category; and
- Service-delivery-level performance measures defined for each constituent of a Program Component (e.g., measures appropriate to a specific funded program, or levels of service related to the appropriate maintenance activities).

2.3 Planning and Program Development

The development of the Statewide Transportation Plan and the State Transportation Improvement Program (STIP) are critical to shaping CDOT's approach to asset management. The following sections summarize organizational roles and key business processes and decision points involved.

Statewide Transportation Plan. The Statewide Transportation Plan fulfills CDOT's responsibilities under ISTEA and TEA-21 to develop and periodically update a long-range, multimodal, fiscally constrained transportation plan in cooperation with RPCs in each of the 15 TPRs. CDOT's first Statewide Plan was developed in 1996; the current update (year 2000) analyzes needs and priorities through 2020. The Plan identifies both statewide and regional transportation needs, prioritized to meet fiscal constraints that reflect current 20-year revenue projections.

The Statewide Transportation Plan builds upon the regional plans prepared by the RPCs. Regional plan development considers all applicable modes, including roads, transit, rail, aviation, intermodal connections, telecommunications, travel demand strategies, and bicycle and pedestrian facilities. Objectives of proposed regional projects include mobility and accessibility improvements, promotion of economic growth and development, environmental protection, consistency with the desired quality of life, and contribution to the integrity of a transportation system that meets the TPR's needs. Identification of candidate projects typically entails a number of steps:

- A review of needs and priorities from the previous plan;
- Adjustments for projects that have since been undertaken or included in the STIP;
- Identification of current issues and forecast needs; and
- Consideration of the policies, goals, objectives, and funding targets and constraints identified for the current planning process.

The RPCs review their prioritized needs with the CDOT Regional Transportation Director, who then compiles an overall list of prioritized lists of projects from all TPRs within that Region. Outreach meetings held by CDOT throughout the state provide public input on implications of current policy, high-priority unfunded needs, and desired transportation strategies. Recommended plans submitted by the six CDOT Regions are reviewed by the Statewide Planning Unit and combined with the Transportation Commission's funded statewide programs (Table A) to produce the fiscally constrained Statewide Transportation Plan. The Statewide Transportation Plan is project-based, in that the list of projects included in the Plan are explicitly identified in the ***Fiscally Constrained Project Appendix***. Other proposed projects that cannot be funded in the current planning cycle are listed in a separate ***Unfunded Long-Range Project Appendix***.

While the Statewide Plan is required to be fiscally constrained (i.e., to represent 20-year needs that are realistic in light of projected revenue), CDOT takes steps to encourage project selection based upon merit rather than just eligibility for available funding in a particular program. It does so by aggregating available funds and allocating the pooled funds to programs without specifically relating a funding source to a particular program or project. CDOT then applies a "highest use" concept to draw down available funds for eligible programs by highest system first (e.g., Interstate highway funds, followed by NHS funds, etc.), assuring that outside funding sources are fully applied.

The Statewide Transportation Plan serves several important functions in subsequent program development and policy review:

- It translates statewide transportation policy into explicit long-range priorities and resource allocations of anticipated revenue by the Transportation Commission.

- It consolidates both statewide and regional long-range needs within a single, coordinated planning document identifying program funding targets and specific project selections in the ***Fiscally Constrained Project Appendix***.

- It provides the basis for programming of the six-year STIP and for program budget development in individual fiscal years.

- It establishes a baseline for periodic review of program status, policy guidance, and resource allocation by the Transportation Commission and CDOT, and for amendment or minor updates of the Plan, if needed, prior to the full update at six-year intervals.

- The Plan represents a consistent outlook and methodology, but is flexible in addressing the diverse needs of geographic areas of the state.

  – It can be amended over time to reflect changed conditions, needs, or policy imperatives.

  – Where additional studies are needed (e.g., corridor studies or specialized studies of modal options or of passenger or freight transportation needs), the Plan can accommodate "place-holders" to represent potential projects addressing these needs.

  – CDOT assists TPRs by providing data on project transportation demand (from CDOT DTD) and anticipated funding targets by program (from CDOT OFMB).

- It defines the agenda, priorities, policy goals, and partnership arrangements for subsequent CDOT actions in building, preserving, operating, and maintaining the statewide transportation system.

- It brings together many of the key decisions on policy, process, and information needed for transportation asset management.

STIP and Budget Development – **Overall Program Development**. The Statewide Transportation Improvement Program (STIP) is a six-year projection of multimodal state transportation projects organized by statewide/regional program and funding source, including all state highway and transit projects. The STIP must be fiscally constrained and consistent with the Statewide Transportation Plan; only those projects included in the Plan may be listed in the STIP. The current STIP, which is the first six-year program produced under Colorado's 2020 Statewide Plan, covers FY 2001 through FY 2006. The STIP is a staged program: Proposed project expenditures in the first half of the program are identified for each of the fiscal years 2001 through 2003; in the second half of the program, only aggregate three-year amounts are shown for FY 2004-2006.

The process for generating the Regional components of the STIP is illustrated in Figure 8, and is referred to as Colorado's Project Priority Programming Process ("4P") or, traditionally, as the "County Hearing Process." An updated process was instituted in 1994 to respond to program development requirements in both state and federal law with respect to regions and metropolitan areas. The STIP is updated according to this process every two years.

Statewide funded program components of the STIP are developed directly by CDOT Regional and headquarters staff with the help of management system analyses, infrastructure condition assessments, performance measures, and Maintenance Program levels of service. Investment choices are investigated within the context of the Investment Category structure discussed earlier. Statewide programs are not subject to the 4P process.

The remainder of the discussion focuses on the Regional component of the STIP that is addressed through the 4P process in Figure 8.

4P Process. STIP development at the Region level builds upon draft Transportation Improvement Plans (TIPs) developed or updated in each TPR, consistent with the Statewide Transportation Plan. TIP development takes place at county or regional meetings designated in blocks A through C of Figure 8. County and municipal officials, the Regional Planning Commission, other public officials or stakeholders, and interested individuals or

organizations may attend these meetings, with required attendance by the appropriate Transportation Commissioner(s) and Regional Transportation Director. The purpose of these meetings is to reach consensus on projects that will be included in the TIP and the STIP, consistent with funding targets and the Statewide Plan.

These meetings also afford the opportunity for CDOT to work with designated Metropolitan Planning Organizations (MPOs) to develop metro-area TIPs as required by ISTEA and TEA-21. MPOs in Colorado are designated in the Denver region (Denver/Boulder/Longmont), Colorado Springs, Fort Collins/Greeley, Pueblo, and Grand Junction.[4] In those TPRs that contain an MPO, the MPO takes the lead in developing the TIP for the urbanized area, and that TIP is reflected in the STIP. For other areas of the TPR outside the urban boundaries, CDOT takes the lead in developing the TIP for that area in cooperation with the MPO.

The next steps in Figure 8 relate to checks of consistency of the TIPs and the STIP with the Statewide Transportation Plan. A STIP project must be included in the Statewide Plan. Among other criteria, if the project cost estimate in the STIP does not exceed the Statewide Plan estimate by more than 30 percent after inflation is accounted for, the STIP project is judged to be consistent with the Plan.

Final steps in the process in Figure 8 include a statewide meeting on the draft STIP chaired by the Transportation Commission; approvals of MPO TIPs by MPO boards and the Governor; adoption of the final STIP by the Transportation Commission; and submittal of the STIP to the FHWA and FTA for approval.

[4] MPOs in the Denver region, Colorado Springs, and Fort Collins/Greeley represent air quality non-attainment areas, a designation that imposes restrictions on projects that can be approved in those areas, and requires updating of the metropolitan transportation plan every three years rather than six years.

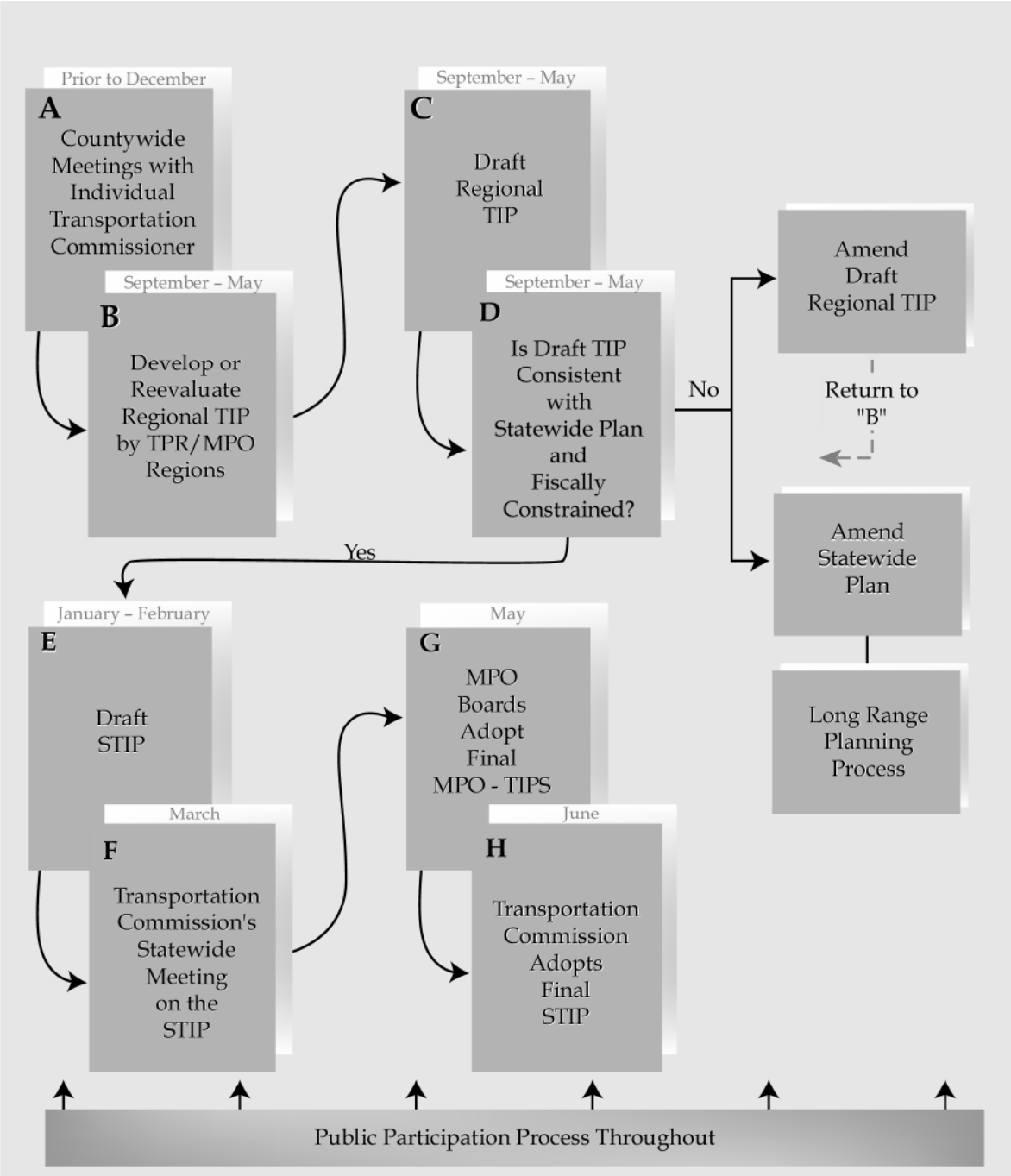

Figure 8. CDOT Project Priority Programming Process ("4P")

Budget. Project amounts listed in the first year of the STIP constitute CDOT's program budget for that fiscal year. A project must be included in the STIP in order to be budgeted.

2.4 Program Delivery

Mechanisms. CDOT has shown a willingness to use a number of mechanisms of program or project delivery to meet the requirements of particular situations: e.g., need for specialized skills, unique complexity or time requirements of a project, lack of suitable resources in CDOT, or desire to achieve greater cost economy. Examples of delivery mechanisms used by CDOT that go beyond conventional approaches to construction and maintenance projects include the following:

- Adoption of a "cradle to grave" project management approach in which Regional engineering and project staff are organized within Program Engineer Units combining traditional pre-construction and construction activities. Project Teams are now responsible for projects from inception to completion, and are expected to provide a more holistic, coordinated, and timely approach to project management.

- Use of innovative construction contracting mechanisms (design-build) and financing agreements among federal, state, and regional/local agencies on the highway and transit components of the Southeast Corridor Project, one of the 28 Strategic Transportation Investment Projects.

- Use of intergovernmental agreements and contracts with the private sector to perform maintenance services in situations where work is more economically or conveniently done by these other entities.

These mechanisms indicate flexibility in addressing unique project needs and a desire for long-term improvement through the definition of Program Engineer Units and Project Teams. However, accountability for achieving the intended goals of a program and for comparing different methods of delivery depend upon reliable statistics on target versus achieved results, and methods to deal with changed conditions when they occur. These matters are typically addressed in DOTs through *tracking* of program delivery and *amendments* of project scope, time, and cost when needed.

Program Tracking and Amendment. CDOT's financial revenues and expenditures are monitored with the help of the Colorado Financial Reporting System (COFRS). COFRS records all CDOT receipts and expenditures by fund and source or program, type of expenditure, and breakdown by object and function. These data are used for financial tracking and reporting, including comparisons with budget amounts and preparation of year-end statements and balance sheets. The status of a given project or program at any time during the fiscal year can be determined through reports or queries of COFRS data. Budget data for the current fiscal year are contained in CDOT's Promise database, discussed in Section 2.5.

Changes in program projects, when needed, can be accomplished through STIP amendments. Two types of amendments are recognized by CDOT: administrative amendments and policy amendments.

Administrative amendments are more common and deal with minor funding or scheduling changes that do not result in major revisions or impacts to other projects. Examples of administrative amendments include the following:

- Movements of projects or funds among the first three years of the STIP;
- Adjustments in project cost due to bids lower or higher than the engineer's estimate;
- An increase in project cost of more than 15 percent if it does not affect negatively the financial feasibility of another project;
- Addition or deletion of projects less than $500,000;
- Changes in the Surface Treatment Program;
- Changes in responsible agency or funding source affecting a project; and
- Amendments initiated by an MPO to its program.

Administrative amendments are processed monthly and can be approved by the Director of OFMB.

Policy amendments deal with more substantial changes and are much less common. Examples include changes in the priority or scope of a project, increases or decreases in the cost of a project that exceed five percent of the total funds available in that program, and any other amendment that does not qualify as an administrative amendment. Policy amendments must go through a formal public review and comment process and are processed biennially.

CDOT's STIP amendment mechanisms are limited to policy and administrative amendments, and do not include additional gradations of change. As a counter-example, systems used by other DOTs might allow for four or five degrees of revision in cost, schedule, and scope during design or construction. Responsibility for review and approval of increasing levels of change (expressed, for example, as a percentage of project baseline values of duration or cost) in these other cases would lie with DOT managerial, executive, Transportation Commission, or legislative committees, respectively.

On a related point, CDOT does not appear to use formal scope definitions that define explicitly the anticipated work, cost, and schedule of a project as part of initial STIP development. Such scoping documents could serve as a baseline for subsequent tracking of project delivery and documentation of revisions. CDOT's planning and STIP databases have been designed to associate a single project number with a given project throughout its life cycle, providing continuity from long-range planning through STIP development to project implementation and completion. It does not appear, however, that this characteristic has been employed to develop planned-versus-actual statistics on overall program delivery.

2.5 Management Systems and Information

Several management systems and databases used by CDOT are important to asset management. Broadened application of these systems, additional improvements in systems features and capabilities, and integration of systems logic or data could further advance CDOT's asset management practice. The following sections summarize the major systems capabilities and their status regarding asset management.

Data Warehouse. CDOT has been developing a comprehensive departmental data warehouse for more than 10 years. The design of this data warehouse calls for information on virtually all of the Department's internal and external business processes:

- **Colorado general information –** e.g., county information, historical information
- **CDOT organizational information –** organization chart, position requirements, departmental policies
- **Human resources –** departmental staffing levels, employee classification, employee listing, individual employee records and histories (compensation, leave, performance, training, medical, etc.), workman's compensation information
- **Financial –** financial accounting (revenues, expenditures, fund transfers, grants, damage claims), budget, payroll, procurement, indirect cost allocation, materials and supplies inventories/stores, fixed assets (non-highway buildings, furniture and equipment)
- **Projects –** construction project pipeline; project data, design data; right-of-way inventory; project agreements; project contract data; project histories, engineer's estimates and bid tabulations; project materials test data
- **Equipment –** departmental vehicle inventory, usage, maintenance, fuel
- **Transportation infrastructure**:
  - **Highway inventory –** HPMS data (100 percent sample), segment definition and location, segment classification, structural and operational characteristics, traffic volumes (AADT), locational information, railroad crossings
  - **Safety –** location, number, type/severity, time of crashes; crash circumstances and factors
  - **Transportation infrastructure management –** pavements, bridges and other structures (including border structure information), signs, access control points, intersections, inspection histories

- **Highway maintenance –** roadway surfaces and shoulders, roadsides, drainage, structures, traffic features, tunnels, rest areas, maintenance yards and equipment; maintenance labor, equipment, and materials costs
- **Environmental impacts –** sites of potential impacts regarding hazardous materials, ecological impacts, cultural impacts, noise pollution; project review information
- **Customer event tracking –** complaints and resolutions

Several of these modules have been completed or are now under development. One major area that is not now addressed in the data warehouse, however, concerns the infrastructure management component. The analytic and informational capabilities associated with this component have been assumed to date by stand-alone information and decision support tools, such as CDOT's pavement management system (PMS), its Pontis® bridge management system (BMS), and its maintenance management system (MMS). These infrastructure management systems are stand-alone applications, each with its own development history, database, analytic engine, and reports. Data used by each system are updated by periodic surveys or inspections of asset condition. Following are descriptions of the relevant features of each of these systems.

Infrastructure Management Systems – **Bridge Management – Pontis® Capabilities**. The Pontis® Bridge Management System (BMS) is designed to assist an agency with recommendations for bridge maintenance and capital improvement projects. Pontis® is now licensed through the American Association of State Highway and Transportation Officials through its AASHTOW are program to over 40 state DOTs and other agencies, including CDOT.

Pontis® supports the entire bridge management cycle, allowing user input at each stage of the process. The system organizes an agency's bridge inventory and records biennial and special inspection data. Once inspection data have been entered, Pontis® can be used to formulate systemwide preservation and improvement policies that evaluate bridge needs according to economic and technical criteria. Pontis® analyses can be applied to recommend projects for inclusion in an agency's capital plan for deriving the maximum

benefit from limited funds. They can also be used for maintenance tracking and federal reporting. Pontis® analyses can integrate the objectives of public safety and risk reduction, user benefit, and preservation of investment to recommend budgetary, maintenance, and program strategies. It thus can provide a systematic procedure for the allocation of resources to the preservation and improvement of the bridges in a network.

Figure 9 shows the framework Pontis® uses in recommending projects for an agency's capital or maintenance programs. In making project recommendations, Pontis® distinguishes between preservation and improvement projects. Preservation projects consist of bridge maintenance, repair, and rehabilitation (MR&R) actions performed on individual bridge elements. Pontis® models how MR&R actions improve element condition, as well as how bridge elements deteriorate over time in the absence of MR&R actions. The overall objective of preservation projects is to maintain bridges at minimum long-term cost, without altering the bridges' functional aspects. Example preservation projects include replacing a bridge deck or repainting a bridge's painted steel elements.

Improvement projects alter functional aspects of a bridge. These projects are intended to address functional shortcomings. To develop improvement projects, Pontis® identifies instances where adequate standards are not met, develops strategies to meet them, and prioritizes the candidate improvements. Example improvement projects include widening a deck, or raising a bridge to gain added vertical clearance, or strengthening a bridge to carry heavier loads.

Pontis® uses a comprehensive set of preservation models to determine the optimal MR&R policy for each bridge element. The deterioration and cost models are initially based upon expert judgments. As an inspection history is developed and maintenance actions are recorded in the database, Pontis® can update the deterioration and cost models based on the historical data. Pontis® uses the deterioration and cost models to perform the preservation optimization using a Markov decision model. The result is a recommended MR&R policy for minimizing long-term preservation costs for each bridge element.

The results of the preservation optimization, along with additional data on the agency's budget and the agency's policies and standards, are used as inputs to the program simulation. In the program simulation Pontis® develops a list of recommended projects which can include both preservation and improvement actions, or can address preservation actions separately from improvement actions. The agency then uses the Pontis® recommendations to develop the actual plan. As preservation and improvement projects are performed, data on project scope and costs are entered into Pontis® for use in recommending future plans.

Besides the agency's budget, a number of additional simulation constraints may be specified to help generate projects that reflect the real-world conditions under which agencies operate. These include:

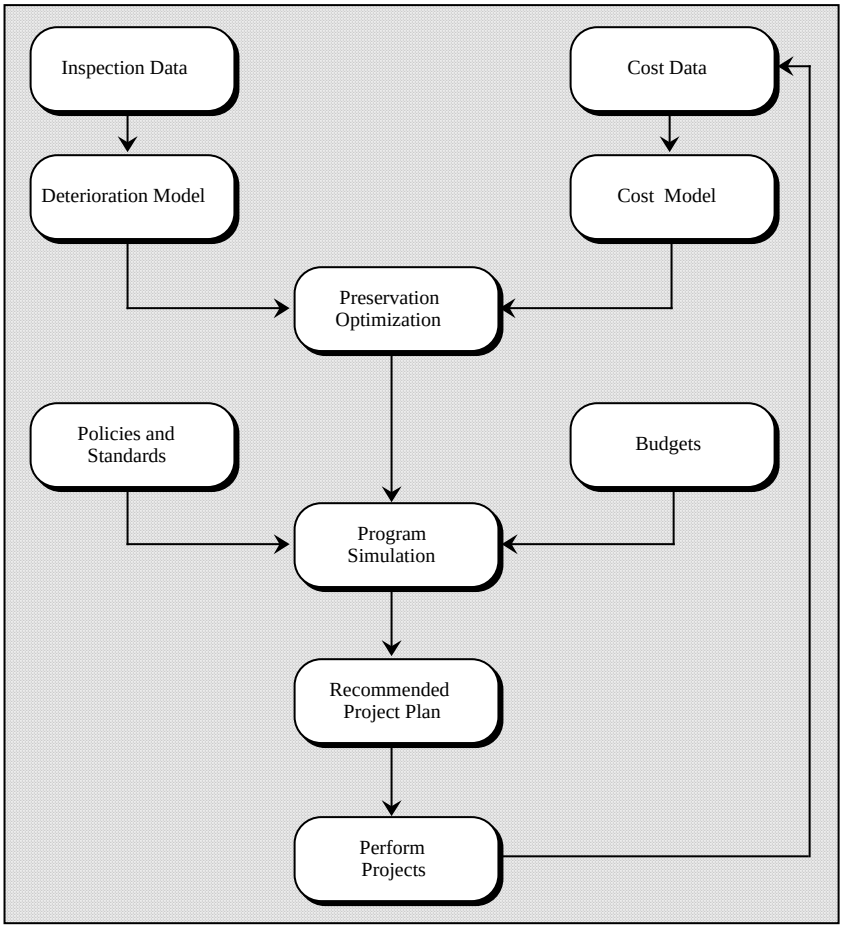

Figure 9. Pontis® Modeling Framework

- **Minimum project cost –** Work is deferred until future years if the sum of the costs of recommended actions on a structure is less than this value;

- **Minimum action cost –** Individual preservation actions are deferred if their cost is less than this value;

- **Deferment years –** After a project has been performed on a structure, work may be deferred for a specified number of years; and

- **Replacement threshold –** If the cost of preservation actions for a structure exceeds a specified percentage of the replacement costs, a replacement alternative is triggered. However, this alternative is suppressed if the candidate replacement project fails to meet certain other criteria.

The simulation generates project recommendations for each structure in a network for each program year simulated. Pontis® aggregates the project-level results to derive network-level results of needs, recommended work, and projected benefits of doing the recommended work. Pontis® also stores the project-level results for use in project planning.

CDOT Application of Pontis. CDOT now uses Pontis® as a database repository for inventory and condition information on state-owned ("on-system") and local ("off-system") bridges. Part of this information is shared with maintenance management for performance-based budgeting, as described below. CDOT to date has not made significant use of Pontis' analytic capabilities, however, for scenario testing in relation to program development.

Pavement Management. CDOT's Pavement Management System (PMS) assists the agency in tracking current pavement condition and estimating future needs to maintain the pavement network according to specified performance goals. Current pavement condition is established through annual inspections of 0.1-mile sample sections in designated lanes of each state highway. Several aspects of surface condition are monitored, including roughness, rutting, faulting of rigid pavements, degrees of cracking and patching, and other surface and materials defects.

These condition data are stored and can be incorporated within various statistical calculations along a route or within a region: e.g., maximum and minimum values, and averages and variances. One or more individual condition values are also combined and normalized within performance indexes, each defined on a scale of zero (poor condition) to 100 (excellent condition). These indexes help relate current pavement condition to threshold values that imply the need for remedial work and that, when reached, signal the need for site investigations to determine the best remedy. For example, indexes defined for flexible pavements include a Rideability Index (based on roughness), a Rut Index (based on rutting), and a Crack Index (based on various categories of cracking). A corresponding set of indexes is defined for rigid pavements. The time at which each index is forecast to reach its respective threshold value determines the remaining service life (RSL) for that measure. The minimum RSL among all indexes for a pavement determines the remaining service life of the pavement overall.

Measures such as RSL and Rideability provide an overall assessment of pavement condition from a customer perspective, and are used to report and forecast pavement network performance with respect to goals established by the Transportation Commission. An optimization process is run within the PMS to estimate the distribution of future pavement surface condition in terms of percent Good, Fair, and Poor pavements as a function of different budget levels. These estimates can be translated into dollar needs and resulting pavement condition by CDOT region. Additional breakdowns of these results are available by functional class of highway. In addition to these network-level results, the recently implemented version of CDOT's PMS considers individual pavement projects and maintenance activities.

Maintenance Management. CDOT's Maintenance Management System (MMS) tracks expenditures and accomplishments by activity as organized in nine maintenance program areas:

- **Planning and Scheduling** (including related meetings, inspections, and leave reporting);
- **Roadway Surface** (pavements and shoulders);

- **Roadside Facilities** (e.g., drainage structures, fences, slopes, litter pickup);
- **Roadside Appearance** (primarily vegetation control and landscaping);
- **Traffic Services** (signs, signals, lighting, guardrail, pavement markings);
- **Structure Maintenance** (bridges, major culverts, approaches);
- **Snow and Ice Control** (plowing, deicing and anti-icing, snow fences, avalanche control, post-storm cleanup);
- **Materials, Equipment, and Buildings** (rest areas, maintenance yards, handling of materials stockpiles); and
- **Tunnel Maintenance** (structural and systems maintenance, operations monitoring).

Data on maintenance performance and costs are tabulated within the MMS based upon field reports ("green cards") filed by maintenance crews. The green cards identify maintenance activity and location, and the labor, equipment, and materials resources used. These data are processed by the MMS and summarized by program area, activity, and maintenance section monthly and annually. Within the past two years the MMS has been upgraded to a Windows™, Y2K-compliant platform.

CDOT has supplemented the MMS with a performance-based budgeting tool that incorporates explicit levels of service related to the condition of highway maintainable items and to levels of activity performance or responsiveness. To support this approach, annual surveys of highway maintenance condition are conducted on a randomly selected sample of highway segments or features. These data establish a baseline of current highway condition, which can be converted to a current maintenance level of service. Future target levels of service can then be investigated in terms of projected maintenance budget and improvement in highway condition. Ultimately, maintenance levels of service will be related to performance measures developed in CDOT's Investment Category structure described earlier.

The maintenance level-of-service approach has prompted efforts to make use of data from other CDOT infrastructure management systems. To date advances have occurred with the Pontis® BMS, by which data on bridge condition (for those elements in a condition state that makes them candidates for maintenance) are applied directly to determine current level of service. Similar integration with PMS data remains an objective for the future.

Geographic Information System (GIS). A geographic information system (GIS) can serve as a platform to integrate information from asset management systems and other sources of relevant information. CDOT has had a GIS operating within DTD for several years, and the system is widely accessible by CDOT staff. The GIS displays information on highway and aviation transportation assets, and is updated though links to the data warehouse and databases associated with individual management systems. GIS is now applied to a number of objectives, including analyses of environmental impacts, project scope studies, identification of maintenance and bridge needs, and planning studies.

CDOT is now engaged in a pilot study in Region 2 to assess the usefulness of the GIS at a level of engineering precision in the context of corridor studies. To date, this effort has been successful. The next step will be to investigate GIS support for engineering at a project level.

Efforts are also underway to broaden the usefulness of GIS to a wider audience within CDOT. This effort entails promoting GIS information as an asset, strengthening its analytic capabilities to be of use to a number of groups, and to provide information in a way that assists high-level decisions. Greater use of GIS on the Internet and continued development of web-based tools, user ability to obtain customized maps and ad hoc reports, data mining capabilities, and the combination of GIS tools with complementary analytical capabilities of specialized management systems also point to growing uses of GIS at CDOT in the future.

Budget and Financial Management. CDOT's financial management systems provide information on the funding and expenditure dimensions of asset management:

- The COFRS system stores and processes expenditure data for the entire Department by fiscal year. COFRS data can be used to infer "true" costs of asset management activities that include indirect cost components or other adjustments that are not accounted for in infrastructure management systems. Such an adjustment is now performed in Maintenance program performance budgeting. The COFRS totals for CDOT highway capital and maintenance programs can also serve as the basis for current expenditures needed in financial reports (refer to Section 2.6).

- The ProMIS database, which is part of CDOT's data warehouse, enables automation of STIP program building, processing of budget and obligation transactions, comparisons of budget requests with corresponding estimates, tracking of expenditures, and automated reporting between CDOT and the FHWA.

Customer Surveys. In addition to data collection efforts conducted in association with each of the infrastructure management systems described above, CDOT also conducts periodic surveys of highway users – its customers. Questions are posed to different user groups (e.g., metro and non-metro residents) regarding the condition of various highway features and quality of services. These data are tabulated and summarized, and can be compared both cross-sectionally across different groups of respondents and in time-series against previous survey results, to assess degree of improvement and relative priority of needs as perceived by the public.

2.6 GASB Standards

The Governmental Accounting Standards Board (GASB) has recently issued Statement 34, updating the standards applicable to financial reporting by state and local governments. Among its many provisions is a change requiring inclusion of transportation infrastructure assets – e.g., roadways and bridges – in an agency's financial reports. GASB allows two methods by which data applicable to transportation systems may be reported: a depreciation approach, and a modified approach that takes full advantage of an agency's management systems to provide key data.

CDOT has elected to use the modified approach for its pavements and bridges, and is now working to develop the needed information in the following areas:

- A valuation of current transportation assets;
- Identification of current asset condition and applicable expenditures; and
- Statements of goals or targets governing future infrastructure condition, and estimates of the expenditures that will be needed to meet these goals.

CDOT will use its records of infrastructure construction, historical cost trends, expenditure data on its capital and maintenance programs, and predictions by its infrastructure management systems, to develop the information needed in these reports.

3.0 Other States' Experience

3.1 Nature of Review

Several state DOTs were visited to obtain comparative information on how these agencies are dealing with asset management. While transportation asset management is still a nascent discipline, these agencies may be regarded as "leaders" in that they have taken proactive initiatives in asset management as an overall departmental initiative, or they have at a minimum made significant advances in infrastructure management that strongly reinforce the objectives of good asset management practice. The states visited are Arizona, California, Michigan, New York, Pennsylvania, and Washington State.

- New York State DOT has had an active asset management program in place for several years. Michigan DOT has been pursuing several business process and information technology advances since the mid-1990s, which have now been folded into a departmental asset management initiative.

- Arizona DOT and PennDOT are just beginning their development of an asset management plan and strategy, and therefore are in a position comparable to that of CDOT.

- Washington State DOT (WSDOT) and California DOT (Caltrans) manage highway systems with significant structures, traversing a wide range of climate and terrain. WSDOT over the past decade has implemented both a renewed programming process for its highway capital programs and a level-of-service-based performance budgeting process for its maintenance program. Caltrans is now implementing a comprehensive level-of-service approach to its maintenance program.

In addition, the consulting team has supplemented these findings with background information from the national asset management study (NCHRP Project 20-24(11)), from previous engagements with transportation agencies (e.g., in studies of capital programming, maintenance management, performance-based planning, and other topics relevant to asset

management), and material from other sources such as asset management workshops, conferences, and surveys.

As a general comment, it is clear from the interviews that there is no one, single, "correct" approach to asset management. Rather, the practice must be evaluated in the context of several factors affecting the agency's infrastructure and its management principles and culture, including:

- Maturity of the transportation system and factors affecting system demand;
- State and departmental policy goals, objectives, and issues;
- Funding levels and mechanisms, including legislatively mandated projects and resource caps;
- Degree of agency centralization, and evolution of organizational roles and responsibilities; and
- Institutional and interjurisdictional relationships.

These factors influence both the condition and performance of an agency's infrastructure, and how the agency approaches managing, investing in, and operating that infrastructure. For example, institutional and funding considerations delimit the agency's latitude in defining alternatives and making decisions. Policy goals and objectives influence the priorities of actions and choices. An agency facing significant population and economic growth pressures, such as Arizona DOT, defines and approaches asset management differently (e.g., with respect to system expansion and improvement) from an agency where deteriorating infrastructure and constraints on additional system expansion tend to focus choices on preservation (a situation faced by New York State DOT, for example).

Nonetheless, there are several useful examples of practices among the states interviewed that can contribute to improved asset management. These are presented in the following section. In this section we also cite comparisons where appropriate between practices in other states and those in CDOT, including instances in which particular subjects of interest

to CDOT in this study may not have been observed in the state DOTs interviewed. In a later discussion we will identify potential challenges to asset management implementation that likewise have been observed during work on this task.

3.2 Practices Applicable to Asset Management

Improved Planning, Programming, and Monitoring. **Performance-Based Planning and Programming.** While many state DOTs are implementing performance measures within planning and programming, Washington State has recently done so within the context of a completely renewed and integrated long-range planning and capital programming process. Key elements of this process include the following:

- Vertical integration and consistency throughout the process, from policy guidance through definition of planning service objectives, formulation of prioritization formulas, and definition of system performance measures.

- Prioritization formulas and project selection criteria for all programs based upon a benefit-cost criterion where possible, supplemented by additional considerations as appropriate (e.g., environmental impacts, intermodal connections, network connectivity, contribution to economic opportunity). These formulas and criteria help to rationalize the allocation of funds for statewide projects. However, the implications of these allocations are modified by "hold harmless" or other guaranteed distributions of a portion of program funds to DOT regions, apart from the statewide competition.

- Performance-based planning employing specific service objectives in each program area. While its long-range plan might now be considered a policy plan, WSDOT is considering moving toward a project-oriented plan. WSDOT is now working with the University of Washington to investigate methods for multimodal tradeoffs in its planning process.

Strategic View of Transportation System. We did not identify in the DOTs interviewed a formal tiering process for the transportation system analogous to that proposed by CDOT in

this project. Caltrans employs several individual classification schemes for particular programs. Its highway maintenance classification, comprising three classes of roads denoting relative priority, is based upon highway functional classification and is a simple example of tiering. Other examples in Caltrans, such as its High Emphasis Interregional Routes and a subset, High Emphasis Focus Routes, denote relative priority for investment in future statewide programs to bring these routes to a uniform defined standard. These classifications are based, however, more on programmatic designations rather than upon specific, objective highway characteristics and usage, as anticipated in CDOT's tiering process. These Caltrans route designations also correlate in some degree with designations based upon statewide policy goals: e.g., Intermodal Corridors of Economic Significance, and Transportation Gateways of Statewide Significance.

Several states are moving from a view of projects as individual elements of a program to a more strategic approach that groups projects for consideration by corridor or another logical set: e.g., joined sections of two or more routes or corridors. This approach helps maintain network connectivity and consistency of route characteristics, and may reduce the number of road occupancy periods for construction.

Executive-Level Program Review. New York State DOT has instituted an executive-level body to review its transportation program submittals just prior to final recommendation. The Capital Program Management Team comprises the First Deputy Commissioner, the chief of staff, chief engineer, and managers from planning, communications, budget and finance, and the chief counsel (for contracting and procurement). The purpose of its review is a high-level, performance-based, non-technical assessment of forecast program accomplishment and comparison with past trends, to judge whether established program targets are or are not being met statewide, and to determine the causes of identified problems. The review integrates pavement and bridge program recommendations, and is accomplished in conjunction with executive-level performance standards and integrated management system support, as discussed separately in sections below.

Performance Measures. State DOTs generally are focused on developing performance standards to assist long-range planning and program development. While the technical

definitions of these measures differ among states to reflect particular standards, measures of deterioration, management philosophies, customer perceptions, or data collection methods, overall they are similar in nature to one another. Where state practices diverge more fundamentally, however, is in the ability to relate performance measures to broader policy goals and objectives that govern respective programs. WSDOT's experience, for example, indicates that consistency between overall policy and more detailed program elements (planning service objectives and prioritization formulas as well as performance measures) must be a conscious objective in the structuring of program categories and procedures. No DOT that was interviewed has a program structure analogous to CDOT's Investment Categories, a device that helps ensure this consistency.

New York State DOT has, in its asset management approach, supplemented technical performance measures with executive-level measures that identify quickly the status of current and forecast program accomplishment by program and geographic region (e.g., counties). For example, the following measures can be easily color-coded and displayed on a map for NYSDOT's pavement and bridge programs:

- Last program OK, this program OK;
- Last program not OK, this program OK;
- Last program not OK, this program improving;
- Last program not OK, this program worse; and
- Last program OK, this program not OK.

Note that these measures capture simultaneously the satisfaction of a target and the direction of a trend. Targets are established by NYSDOT for pavements and for bridges based upon defined condition standards, analogous to those used by CDOT in its pavement and bridge programs. Decisions on which pavements and bridge projects should be recommended in a given program, and coordination among these projects where appropriate, are resolved by technical managers prior to submitting the program to the Capital Program Management Team for review (refer to prior section). The Team considers the recommended program accomplishments overall in light of the five measures above, displayed on a statewide map by county or other geographic division. Where the

result is deemed unacceptable or questionable, the program is returned to technical and regional managers for review and modification as needed.

Proactive Risk Reduction. A theme emerging from practices of the states interviewed concerns an effort to move their program philosophies from a reactive or "worst first" approach to a more proactive, "optimizing" approach. This shift in philosophy takes the following forms:

- **Greater emphasis on preventive preservation and lowest long-term cost**. This approach results directly from the "least life-cycle cost" concept that is the basis of technical and economic analyses of performance, particularly as applied to pavements and bridges, but also with growing applications to other highway features such as pavement markings. While pavement and bridge management systems have long been based on assumptions of least life-cycle cost or long-term cost-effectiveness, DOTs may have had to incur backlogs in needed work because of resource constraints or other limits on optimal preservation strategies. Moving to a preventive approach is justified economically and technically. However, it is a politically difficult decision because it entails a short-term increase in cost to reduce the backlog to manageable proportions, and it implies preventive work on road features that are still in good condition while damaged features (former candidates for "worst first" funding) may receive reduced or no investment short-term. WSDOT and Michigan DOT have addressed this issue through analytic studies communicated to their governing bodies in support of the change in philosophy to the least life-cycle-cost approach.

- **More effective accident risk reduction**. Safety projects have traditionally been based upon projected accident reduction in demonstrably hazardous locations or corridors, and in blanket risk reduction efforts – the latter prompted, for example, by federally mandated safety improvements associated with highway rehabilitation projects (e.g., need for clear zones adjacent to shoulders). WSDOT has worked with its FHWA division office to promote a more focused approach to accident risk reduction, based on analyses of the likelihood of future accidents at particular locations or under particular conditions. WSDOT and the FHWA have negotiated, as part of their stewardship

agreement, provisions to fund pre-emptive safety projects at these locations where their impact holds greatest likelihood of preventing future accidents. This is in contrast to a broader application of safety funds along an entire route length, where impact on ultimate performance may vary.

- **Earlier environmental reviews**. In areas of environmental sensitivity, reviews of projects and challenges to their environmental acceptability can consume significant time and delay a project schedule by months or years. A unique construction project undertaken by WSDOT entailing a public-private partnership experimented with, among other facets of project delivery, an earlier environmental review. The start of this review coincided with initiation of preliminary project design, rather than waiting for completion of some percentage of design as might occur in conventional projects. The case study indicated that potential issues were identified earlier, and that project design could accommodate environmental mitigation more economically and effectively.

Better Information and Analytic Capabilities. **Next-Generation Management and Data Systems**. DOTs are dealing with how to update legacy systems that would play a strong role in asset management. The strategies available to accomplish this differ widely. At one end of the spectrum is a complete rewrite of asset management systems or databases as has been undertaken by Michigan DOT. At the other end are more selective and limited actions such as system updates, system and database integration, and new development of specialized tools and procedures, as have been pursued by Caltrans, WSDOT, Arizona DOT, and NYSDOT. Apart from this difference in approach as to how to obtain the systems and data capabilities needed for more effective management, the following themes emerge:

- **GIS platform for integration**. New York State DOT now integrates its pavement management and bridge management information on a GIS platform as part of its asset management development. A typical display shows a map with the highway system, on which are superimposed color-coded symbols indicating pavement or bridge projects, respectively. Double-clicking on a project symbol opens a window displaying detailed information on the project. An analogous approach is now under development in

Michigan DOT and Arizona DOT. MDOT has compiled a unified data repository, and ADOT is designing and developing a data warehouse, both of which will consolidate asset inventory information and potential project information from asset management systems. These centralized data collections will communicate with a GIS to display asset information spatially.

- **Executive-level information**. Most states employ asset management systems: particularly for pavements and bridges, but also for safety, public transit, intermodal facilities, other system features and appurtenances, construction projects, maintenance, and traffic operations. Surveys conducted by the National Cooperative Highway Research Program (NCHRP) and by the FHWA indicate that these systems are widely used for technical and research purposes, including detailed program development. However, their use by higher-level or executive management for decisions such as resource allocation and program tradeoffs is much less frequent. Initiatives in asset management and compliance with GASB Statement 34 (see below) will likely change this outlook. WSDOT has for several years successfully employed an executive information system that provides high-level programmatic and financial information to WSDOT managers and legislative and commission members and staff. WSDOT's maintenance levels of service are likewise implemented in this executive-level system, complete with color photographs illustrating each level of service within a maintenance program area. Users can apply the system to explore budget implications of changes in level of service within each program area. Michigan DOT has been contemplating such a system to build upon its existing asset management applications. NYSDOT's maps of its high-level program performance measures (discussed above) are also an effective illustration of information tailored to executives.

New System Developments. In addition to information and management system developments by state DOTs, the FHWA's Office of Asset Management is also undertaking two major system initiatives that will contribute to asset management.

- **HERS/ST**. FHWA's Highway Economic Requirements System (HERS) is being promoted for state DOT use, a program referred to as HERS/ST. The HERS application is based on the Highway Performance Monitoring System (HPMS) database, and is intended to replace HPMS as the source of biennial federal needs studies submitted to Congress. The HERS algorithms address both highway capacity and pavement preservation needs. Thus, HERS/ST is uniquely suited to asset management studies that are more comprehensive than those addressed by individual management systems (e.g., pavement management and congestion management). For example, HERS/ST could be applied to explore tradeoffs between system preservation and improvement/expansion.

- **Tunnel Management**. The FHWA, in cooperation with the Federal Transit Administration (FTA), is scheduled to award in the near future a project to design a Tunnel Management system. The project entails a number of components:

  – A compilation of data on U.S. highway and transit tunnels, and recommendation of a tunnel database structure;

  – Manuals presenting guidelines for tunnel management; and

  – Preliminary design of a Tunnel Management system, building on the database above, and describing key system components and reports.

Transportation Operations Strategies. Transportation system operations are a component of asset management that is likely to receive increased attention in congested areas and in growth areas. Operations centers have been established in metropolitan areas in several states to provide real-time monitoring of system performance. With the implementation of intelligent transportation systems (ITS), operations managers can issue and coordinate traffic advisories, variable message signs, ramp metering, and other measures of traffic control and guidance. Caltrans has developed formal, comprehensive Traffic Operations Strategies (TOPS) that seek to reduce congestion through improved system management. Elements of TOPS include the following:

1. Completing the "intelligence" component of existing infrastructure;

2. Correcting infrastructure "bottlenecks" at the corridor and system levels through physical improvements;

3. Filling gaps in the high-occupancy-vehicle (HOV) network to eliminate traffic disruptions at merge points with general purpose lanes; and

4. Modifying selected freeway-to-freeway interchanges to minimize traffic disruptions.

These objectives are organized within three investment levels, with initial funding focused on the first level:

- Level 1 focuses on choke points that can be corrected through minor operational improvements: e.g., auxiliary lanes, intersection modifications, and the addition and coordination of intelligent system devices. Level 1 encompasses the first two components listed above.

- Level 2 adds HOV capacity and operational improvements, addressing the third component above.

- Level 3 includes major operational improvements, addressing component number 4 above.

Organizational Practices. Asset management has potentially significant implications for organizational roles and responsibilities and both internal and external communications by an agency. The institution of new business processes, such as the Capital Program Management Team by NYSDOT described earlier, is one example of business process change as a direct result of asset management implementation. More generally, improved asset management techniques have evolved from new business models adopted by agencies that are customer-oriented and performance-based: e.g., the use of input from customer surveys for program and performance evaluation, definition of customer-oriented performance measures for transportation programs, and application of performance budgeting and level-of-service concepts to highway maintenance. Many of these are

already familiar to CDOT, and match developments in states visited. Some additional ideas gained from the state visits include the following:

- **Internal vision workshops**. As part of its development of an asset management strategic plan, PennDOT has held a departmental vision workshop to review the proposed framework, tasks, and intended benefits associated with specific asset management steps. This workshop provided the benefit of both knowledge-building as well as team-building. While it succeeded in communicating what is asset management and its importance to the department, it also fostered the improved communication across departmental units that is needed for successful asset management implementation.

- **Asset management communication package**. Michigan DOT has developed a "marketing" package advertising its activities and objectives in asset management. This color presentation comprises a number of "fact sheets" summarizing key topics and activities. Individual sheets present a primer on asset management, descriptions of key management systems, an overview of the process, introduction to asset management as a way of doing business, historical perspective, and descriptions of specific activities.

- **Report cards**. The PennDOT Secretary of Transportation issues a monthly report card to its customers on measures of agency programs and performance. These cover a variety of topics, including roadway smoothness, pothole maintenance, safety of rail crossings, winter services, safe driving statistics, and customer services, among others.

- **Interjurisdictional cooperation**. PennDOT engages in the Agility Program, which establishes cooperative relationships with other jurisdictions to offer seamless transportation services. For example, PennDOT may paint markings on a township's roads while the township mows grass on a state highway within its jurisdiction.

GASB 34 Reporting Compliance. As of the dates of the respective interviews, most of the states visited had decided to conform to GASB 34 standards using the modified method. Several (e.g., Caltrans, ADOT, MDOT) are now working through the details of identifying

the sources of the specific information and the nature of the calculations and adjustments needed to produce the requisite reports and supplementary information.

3.3 Challenges to Asset Management Implementation

One of the findings in the national (NCHRP) asset management study is that private sector firms that practice asset management exhibit a high degree of alignment in their policies and practices: i.e., the importance of asset management to a company's operations and profitability is clear throughout the organization, and both corporate and individual incentives are aligned to promote highly effective management practices. Part of the challenge of implementing asset management principles in the public sector is the nature of a transportation agency's organizational, institutional and financial environment, coupled with constraints imposed by other bodies. Characteristics of this environment that can impede asset management include the following:

- Responsibility for different modes or for different segments of the transportation system is fragmented across several agencies.
- Funding is often constrained by mode and function, limiting the latitude by which a DOT could otherwise assign funds to where they are most needed.
- Within a highway transportation organization, the pavement, bridge, maintenance, and other organizational units involved in asset management are not integrated. While channels of vertical communication may be adequate within these areas of core expertise, horizontal communication may be not be sufficient for good asset management, or may not occur at the appropriate management levels.
- Management systems and databases are often stand-alone and of different vintages, complicating issues of system integration and data integrity, accuracy, completeness, and currency.

- Senior management does not have access to sufficient quality information to analyze tradeoffs and make resource allocation decisions effectively, as noted earlier. There are likely a number of historical reasons for this.

- The increased scope and complexity of departmental responsibilities must be balanced against resource limits and imposed constraints. Change management is therefore very much an issue faced by DOTs, but agencies across the Nation have dealt with the problem differently.

As a result of these characteristics, asset management implementation within a DOT will face a number of challenges. For convenience we have organized these below into two groups: institutional, and technical. It is our considered opinion, as well as that of several managers we interviewed, that the institutional challenges are more significant and potentially difficult to deal with.

Institutional Challenges

- To integrate decision-making and allocation of resources across asset classes;

- To combine the financial, management, engineering, and operational perspectives of a department within this decision process;

- To define system performance measures that reflect customer perspective and user costs effectively;

- To secure senior management support and leadership throughout the period of asset management implementation, which may extend over several years; and

- To develop new public and private sector roles that enable an agency to fulfill its mission in the face of change, and to implement these roles effectively.

Technical Challenges

- To integrate "stovepipe" or "silo-based" legacy systems and stand-alone databases established for different asset classes or functions;
- To develop comprehensive, GIS-compatible, enterprise-wide databases that better serve asset management;
- To create next generation management systems or specialized analytic tools that support a wide range of "what-if" analyses reflecting different budget and performance assumptions (e.g., for tradeoff analyses);
- To improve life-cycle analysis methods and incorporate them fully within planning and program development; and
- To strengthen transportation system monitoring capabilities and use of this information for program evaluation and policy formulation.

4.0 Asset Management Plan

4.1 Vision

Foundations. This vision of transportation asset management builds upon CDOT's development of several relevant concepts and methods that have been described in Section 2.0 and are summarized as follows:

- Goals and objectives of asset management are articulated in policies and guidance issued by the Transportation Commission.
- CDOT's Transportation Investment Strategy uniquely organizes capital, maintenance, and other programs within a comprehensive framework embodying goals, objective evaluation criteria, outcome-based performance measures, and customer perceptions.
- CDOT follows a long-range planning process and the 4P program development process within the context of the Investment Category framework. These processes are project-specific, respond to policies and guidance established by the Transportation Commission, and incorporate comments received during statewide public outreach.
- CDOT and the Transportation Commission have adopted a more holistic view of projects through the Strategic Projects program.
- CDOT is moving toward integration of pavement management, bridge management, and maintenance management results through the Investment Strategy and the Maintenance Level of Service efforts to inform planning and program development.
- CDOT's Maintenance Level of Service Program has been integrated with a performance-based budgeting tool that has been successfully applied to Maintenance Program budget recommendations beginning in FY 2001.

- CDOT conducts periodic inspections of its highway pavement, bridge, and maintenance features, as well as customer surveys regarding perceptions of current levels of transportation service.

- CDOT's current updates of its management and information systems will benefit its asset management program. These updates include migration of the maintenance management system (MMS) to a Y2K-compatible Windows™ platform, functional upgrade of the pavement management system (PMS), and pilot use of the geographic information system (GIS) for engineering-oriented applications.

- CDOT has pursued innovative project delivery and financing mechanisms in the form of design-build contracts with both FHWA and FTA funding participation on the Southeast Corridor project.

With this breadth of accomplishment and CDOT's initiative in developing this asset management plan, it can fairly be said that CDOT is in the leadership ranks among transportation agencies nationwide in pursuing asset management. While several of the developments listed above are similar to initiatives pursued by other states, CDOT's Investment Category structure is unique:

- The Investment Category structure integrates several elements critical to asset management within a coherent, overarching framework;

- It structures investments based upon policy objective and impact on performance rather than funding source; and

- It facilitates the analysis of tradeoffs among capital, maintenance, and operations program categories.

The Investment Category structure provides the unifying framework for communicating a vision of asset management at CDOT.

Vision Statement. The vision guiding CDOT's implementation of asset management is proposed as follows:

Transportation asset management represents a strategic approach to managing transportation infrastructure. It embodies a philosophy that is comprehensive, proactive, and long-term with the following goals:

- To build, preserve, operate, and reinvest in facilities more cost-effectively with improved performance;
- To deliver to an agency's customers the best value for the dollar spent; and
- To enhance CDOT's credibility and accountability in its stewardship of transportation assets.

Asset management provides a set of principles that guide an agency in improving how it conducts its business, how it reaches decisions, and how it processes, uses, and communicates information related to the management of its infrastructure. At its core, asset management focuses on an agency's allocation of resources – funding, people and skills, and information. It provides an integrated framework that establishes common approaches across asset classes in planning, program development, and program delivery. It encourages a number of best practices in these processes: e.g., consideration of the full range of alternatives at each stage of decision, effective use of management and information systems throughout, adoption of a long-term view in economic analysis of projects, and evaluation of tradeoffs across programs. Asset management is results-oriented, driven by policy goals and objectives with clear measures of system performance and accountability.

CDOT has already taken a number of steps toward improved asset management. A major development has been the establishment of the Investment Category structure, which organizes program investments within a policy-oriented framework identifying explicit measures of performance. Other CDOT accomplishments complement the Investment Category approach, including updates of the statewide planning process and the program prioritization process, establishment of maintenance program levels of service, institution of customer surveys, and updates of relevant information and database systems. This Asset Management Plan builds upon these established concepts, methods, information, and tools

to propose specific actions over the next five years to build upon and expand these accomplishments. Hallmarks of this vision include the following:

- Completion of all elements of the Investment Category structure, and incorporation of all infrastructure programs, including Strategic Projects, in the Investment Category approach;
- Incorporation of asset management principles in CDOT's planning and programming processes, building on the tiered structuring of CDOT assets recommended in this study;
- Integration of asset management information on a GIS platform, and renewal of Information Technology strategic planning to support asset management department-wide; and
- Strengthening of program delivery mechanisms and measures.

Each of these areas entails multiple tasks that will need to be accomplished. Definition of these tasks, assessment of priority, designation of organizational responsibility, and estimation of the time and cost of accomplishment must take into account the specifics of the current situation and the recommended business process in each of these areas. To illustrate how this is done, the following sections provide examples, for specific program decision processes, of how this asset management vision is translated into specific steps for accomplishment.

4.2 Translating Vision Into Specific Recommendations

Example – Pavement Preservation. The example business process that will be used in this section is program development for pavement preservation. Pavement preservation is a component of the System Quality Investment Category, and encompasses both capital and maintenance work. The pavement example is an important and a relevant one to asset management improvement for the following reasons:

- Pavement preservation is a significant component of CDOT's annual capital and maintenance program.

- Pavement condition strongly affects customer perception of highway condition and of the quality of the job that CDOT is doing.

- The quality of service provided by Colorado's pavements is a focus of attention of the Transportation Commission, which has established explicit targets for statewide pavement condition by highway functional class.

- CDOT has recently improved its analytic capabilities for identifying pavement needs:

  – It has implemented a new pavement management system (PMS) to help identify locations of deficient pavements and to apply the concept of Remaining Service Life (RSL) to predict future needs; and

  – It has also developed maintenance levels of service (LOS) as part of its maintenance management system (MMS), to be able to express the current condition of pavements and other maintainable features, and to relate target conditions to required expenditures in a performance budgeting approach.

- Predictions of the PMS have been called into question at the Region level, based upon comparisons with actual projects programmed. From an asset management perspective:

  – This matter may indicate need for improvement in the analytic capabilities of the PMS, or in the quality of the pavement condition data monitored in the field; and

  – It may also indicate the need for improved business processes between CDOT Central and Region offices, to ensure closer agreement on pavement project definition.

How these and other factors are accounted for in the asset management review is illustrated by comparing the current pavement programming process with a "straw" proposal of how pavement program development could be accomplished under an improved process conforming more closely to asset management principles.

Comparison – Current and Proposed Program Processes. **Current Pavement Program Process.** The analytic basis of the current pavement programming process is illustrated schematically in Figure 10. This figure is idealized and simplified for the purpose of this example, but it illustrates the key points of interest. Two parallel tracks of program development are shown: one for capital projects based upon application of the PMS; the second, for maintenance work based upon application of the MMS. Within each year, future program needs are projected in the PMS and the MMS tracks based upon the following inputs:

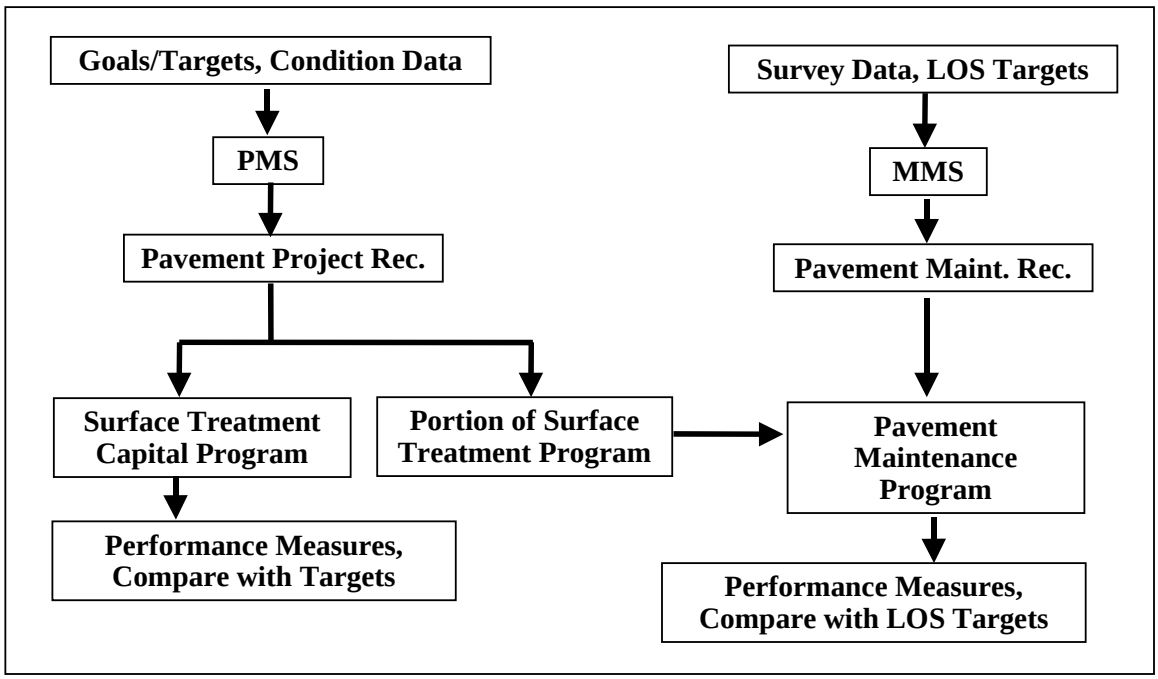

Figure 10. Current Approach to Pavement Program Development and Implementation

- Current pavement condition as established through field surveys of a sample of the network. Separate surveys are now conducted by the PMS and the MMS groups.

- Target level of service or condition, expressed as a policy input. For capital projects managed with the PMS, this target responds to goals set by CDOT and the Transportation Commission, and may be expressed, for example, by adjusting the "trigger values" at which pavement remedial work will take place. For maintenance

activities managed with the MMS, targets are set by specifying future LOS values for each maintainable aspect of pavements.

These inputs are analyzed by the PMS and the MMS, respectively. The PMS employs internal decision procedures to identify those pavement sections where RSL will exceed the trigger value within the timeframe of the program under development. The LOS Budgeting module of the MMS has internal models that relate projected maintenance expenditures for the program under development to a comparison of target versus current LOS. In each case, the systems produce candidate recommendations that can be reviewed by CDOT managers in the Central and the Regional offices. The result of these reviews is a recommended Surface Treatment Program for capital projects and a recommended maintenance program for maintenance activities.

A portion of the Surface Treatment Program goes to fund pavement preventive maintenance as part of the maintenance program, as shown in Figure 10. Notwithstanding this interaction between the two programs, however, the two management tracks are conducted largely independently, with separate surveys, separate inputs of levels of service, and independent analytic techniques. Moreover, once the capital and maintenance work is accomplished on the pavement network, comparisons of resulting system condition and performance to intended targets are likewise accomplished independently by pavement management and maintenance management units. The conclusion is that the program development processes for pavement preservation are conducted in what is often described as a “silo” or “stovepipe” process.

From an asset management perspective, silo or stovepipe processes typically do not yield solutions as cost-effective as those produced by a more integrated approach. The reason is that the mix of pavement maintenance and capital rehabilitation or reconstruction activities have not been subjected to a life-cycle cost analysis. Such an analysis, investigating the tradeoffs between capital and maintenance actions on pavements, could identify the optimal point at which maintenance is no longer efficient, and capital repairs should be undertaken. Moreover, by unifying the establishment and review of pavement performance measures and pavement maintenance LOS, CDOT could ensure that both capital and maintenance

resources are being applied in the best way to meet the Transportation Commission's goals for pavement condition.

Improved Pavement Program Process

An approach that conforms more closely to asset management principles is illustrated in Figure 11. The process represents a unified series of decisions, rather than in separate "silos." While separate management systems may still be employed for pavement (capital) and maintenance management, the inputs to these systems are developed in a coordinated and systematic fashion. Similarly, outcomes are evaluated in a coordinated fashion to evaluate accomplishment of target conditions and performance and to adjust future targets if needed. The process in Figure 11 can be regarded as a "straw" proposal in that there are variants that would also satisfy good asset management guidelines, but it serves well nonetheless to illustrate the lessons of applying asset management principles. Let us discuss each of the process steps shown in Figure 11 on how asset management can be applied in a practical setting, building upon CDOT's current capabilities.

Goals, Objectives, and Targets

Asset management is driven by policy, expressed through goals established by the Transportation Commission and implemented by CDOT. For pavements, for example, the current goals call for at least 60 percent of the pavement network to be in Good or Fair condition, with individual goals defined by functional class. Indicators of actual accomplishment that correspond to these goals (i.e., percent of pavements actually observed to be in Good or Fair condition) serve as Investment-level performance measures in the Investment Category structure. Thus, a direct linkage exists between the Investment Category structure and the program development process.

Objectives are guidelines to the process. They may represent departmental initiatives or strategies: e.g., to shift from a "worst first" repair policy to a "preventive maintenance" approach, or to apply more cost-effective rehabilitation in lieu of reconstruction. They may also be issued as directives, guidelines, or encouragement of particular practices or technologies: e.g., information on new products or suggestions to use Superpave.

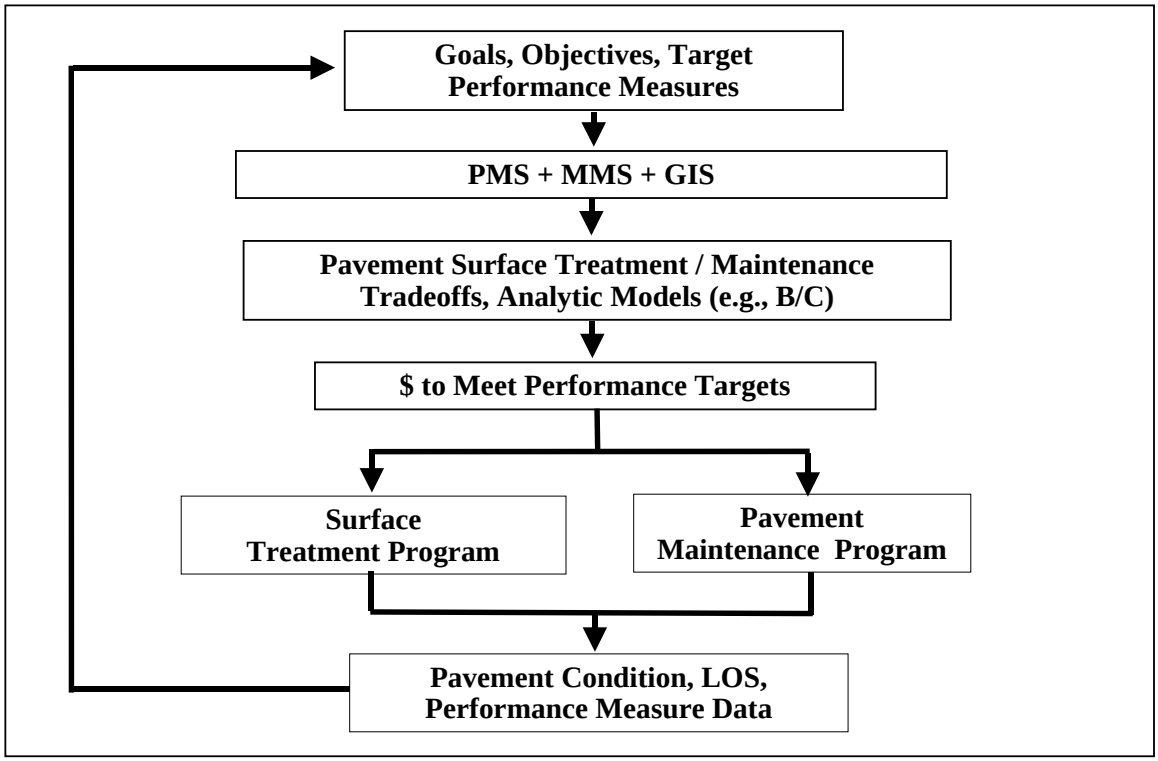

Figure 11. Improved Approach to Pavement Program Development and Implementation

Targets represent proposed values of pavement performance measures or pavement maintenance levels of service that are intended to be achieved in the proposed program. Asset management prescribes a direct linkage between these technical measures of performance and the more general, policy-oriented goals described above. To date, this linkage has been established most closely with the technical measures of pavement condition associated with the PMS. Adding pavement maintenance LOS to this relationship enables a true consideration of pavement life-cycle costs. This more comprehensive linkage between goals and targets can be accomplished in the following ways:

- Incorporate an explicit consideration of the costs and the benefits of pavement maintenance within the PMS analysis. The PMS could then be used to help guide the establishment of target pavement maintenance LOS. This approach may require changes to both the algorithms and the measures of pavement condition in the PMS.

- Develop a separate economic analysis of typical costs and life extensions due to various pavement maintenance, rehabilitation, and reconstruction activities, if these are not available in existing management systems. Use the results of this analysis to develop general guidelines on which activities are economically preferred under what conditions. This analysis could be incorporated within a spreadsheet, for example.

- Apply a separate pavement life-cycle cost package to investigate the issues discussed in the preceding item. Such packages have been developed by the Federal Highway Administration (e.g., HERS/ST, EAROMAR). The advantage of these models over the simpler economic analysis described above is that these models include estimates of user costs or benefits.

Modeling capabilities are useful not only at this step, but later in the process as well when considering capital-maintenance tradeoffs and identification of the optimal long-term pavement strategy. Refer to the sections below entitled *Analytic Models and Tradeoffs*.

Application of Management Systems

The analysis of pavement preservation needs will likely continue to be processed in parallel by PMS and MMS individually, as shown in Figure 11. While fully integrated "total asset management systems" that incorporate pavement, bridge, maintenance, safety, and other infrastructure management capabilities are conceivable and have been proposed, this strategy is expensive, time consuming, and prone to risk. Many of the advantages of full integration can be achieved using individual systems by improving ways in which information is communicated between the different applications.

One key recommendation is to display PMS, MMS, and other management system information on maps produced by a geographic information system (GIS). GIS displays make it easy to highlight locations of deficient pavement condition, display multiple performance measures and targets for each location, relate pavement condition to other network attributes (e.g., daily traffic volume, truck traffic, road functional class, geographic zone, pavement type), and coordinate pavement construction or maintenance work with other project work planned on the route or corridor.

Improved communication between systems can also be achieved by integrating measures of condition, performance, and targets, as discussed above. For example, if the measures of pavement condition and performance used by the PMS were enhanced to be able to capture the beneficial changes in pavement condition due to maintenance, a basis for estimating and communicating recommended pavement maintenance LOS could be developed in the PMS for use in the MMS.

Analytic Models and Tradeoffs – Consequences of Different Funding Levels

One important tradeoff analysis that the PMS and MMS[5] can now perform is to investigate how potential changes in program allocation or funding level will affect resulting system condition. This analysis can inform CDOT decisions on recommended program budget, distribution of program funds among Regions, and responses to questions by the Transportation Commission on the consequences of varying the amount or distribution of program funding. This analysis can be run prior to resource allocation meetings so that options and their consequences can be explored beforehand.

The analysis that would be performed using the PMS and the MMS, respectively, is to relate a number of assumed program funding levels to their resulting pavement conditions.

- The PMS can be used to predict pavement condition as a function of funding level in terms of percent Good/Fair and percent Poor. Within the PMS, the different levels of program funding can be reflected in the input data, either directly as a set of budget constraints or by varying technical inputs that are equivalent to these budget constraints: e.g., different trigger condition thresholds at which remedial work will be done, or different limits on network condition (i.e., the maximum percentage of Poor pavements and the minimum percentage of Good/Fair pavements that are acceptable).

- The MMS reverses this process by predicting the maintenance expenditures required to achieve a given target LOS. A range of target LOS values could thus be specified and

[5] We are referring here to the performance budgeting module, the LOS Budgeting Workbook, that has been created to complement CDOT's MMS.

related to the associated expenditures that are computed by the MMS. The target LOS values can also be related directly to technical measures of the maintained condition of the pavements (e.g., percent of cracks sealed, or percent of defects repaired).

This analysis can be performed with no change to the existing PMS and MMS, and thus could be used as a first stage application of asset management principles to program development in Figure 11. However, this analysis assumes that the funding levels of the capital program and the maintenance program are still independent of each other. A refinement of this approach would consider capital-maintenance tradeoffs as a more advanced stage of analysis.

Analytic Models and Tradeoffs – Capital-Maintenance Tradeoffs

Past research has indicated that a comprehensive program of road surface maintenance can extend service life by roughly two to four years as compared to a policy of no maintenance. A tradeoff therefore exists between an approach that emphasizes maintenance and the benefit of extended service life versus an approach that performs little or no maintenance (with the benefit of annual maintenance cost savings) but that rehabilitates or reconstructs the pavement at an earlier age. Viewed in its simplest form, the problem of determining the most cost-effective level of maintenance service can be solved on an economic basis using life-cycle cost analysis.[6] Alternatively, if a PMS accounts properly for the beneficial effects of routine maintenance on pavement condition and RSL, the decision procedures within the PMS can likewise yield the desired solution based upon the particular decision criteria employed.

CDOT therefore has the following options in implementing analysis of capital-maintenance tradeoffs:

[6] This analysis provides a simplified overall guideline for the most economical approach to preserving pavement structural RSL. A given level of pavement maintenance will often be required for other reasons: e.g., to correct local defects or premature failures, to correct a safety hazard, mitigation of damage due to highway accidents or natural catastrophes, and so forth. These other factors are not accounted for in the analysis.

1. Develop the capability directly within the PMS and MMS. This would require the following system modifications:

   – Building within the PMS the ability to account for the effect of routine maintenance LOS on the condition and RSL of pavements;

   – Applying PMS decision algorithms to recommend an optimal pavement maintenance LOS;

   – Having the PMS communicate to the MMS the optimal pavement maintenance LOS; and

   – Having the MMS communicate to the PMS periodic updates of the cost of pavement maintenance activities.

2. Develop the capability within a specialized application (e.g., a workbook or small computer program). This application would use input data (provided either by automated linkages to appropriate databases, or by manual input) from the PMS and MMS, and perform an economic life-cycle cost analysis. The recommended pavement maintenance LOS would then serve as guidance in subsequent program analyses by the MMS. Corresponding changes in the RSL of pavements would provide guidance in adjusting the rate of deterioration in the RSL models of the PMS.

3. Employ life-cycle cost analyses, such as those developed by the FHWA described earlier, to obtain the recommended pavement maintenance LOS.[7]

These options illustrate different approaches that can be used to achieve improved asset management for this specific objective. The cost of each will differ, and there are different levels of risk associated with each. If CDOT desires to employ capital-maintenance tradeoffs, the recommended approach would be to build essentially a prototype of the

[7] HERS/ST may need to be customized to provide this capability. EAROMAR can analyze different maintenance policies, but these policy inputs would need to be translated into the equivalent LOS values used by CDOT.

analysis using option 2 above. This step can be accomplished at modest cost and at minimal risk, since spreadsheet workbooks or stand-alone applications can be designed economically and can be modified fairly easily to accommodate subsequent changes to design. Following successful use of this application and any final adjustments, CDOT can decide whether to continue to use the application as a stand-alone analysis, or to employ its concepts and algorithms as the basis for design of either option 1 or option 3.

Analytic Models and Tradeoffs – User Costs and Benefits

One additional analytical capability worth mentioning is the ability to assess the impacts of pavement investment and maintenance strategy on CDOT's customers through estimates of user costs.

- Procedures that account for user costs are able to consider minimization of total life-cycle costs. Total life-cycle costs comprise the sum of agency costs (for maintenance, rehabilitation, and reconstruction) and user costs (for travel time, vehicle operation, and possibly accident frequency).

- Optimization of total life-cycle costs is a valid economic criterion that takes proper account of pavement program allocation decisions on CDOT's customers. This approach is most effectively used to consider tradeoffs among major pavement actions: e.g.,

  – Whether to build stronger pavements having longer RSL to lengthen the interval between rehabilitation actions (a tradeoff between initial construction cost versus the stream of subsequent discounted rehabilitation costs); or

  – To evaluate economically the most effective rehabilitation strategy, considering different actions having different costs and extensions to life.

- Pavement life-cycle cost models such as HERS/ST and EAROMAR already incorporate user cost models, and can be applied as supplements to CDOT's existing management systems if user costs are not now included in the PMS and MMS.

- Alternatively, approximations of user costs and benefits can be built into simplified spreadsheet models to analyze general, composite, or typical cases: e.g., by pavement functional class.

Two basic types of relationships are represented in pavement models incorporating user costs: 1) impact of pavement condition on user costs (significant only as pavement condition approaches Poor); and 2) impact of construction and maintenance work zones on user costs (a function of reduction in basic highway capacity due to the work zone, period of work zone occupancy of the highway, average daily traffic (ADT), and traffic peaking characteristics).[8]

Program Dollars to Meet Performance Targets

Given the results of the analyses in the preceding section, CDOT can use this information as guidance in developing a recommended level of funding for pavement preservation. Other factors will also influence this decision: e.g., the projected revenue stream, competing needs in other programs, and policy directives and priorities.

Surface Treatment and Maintenance

The analytic methods above will also provide guidance on a recommended distribution of funding between surface treatment and routine or preventive maintenance. From an asset management perspective, the closer the actual distribution is to the optimal split recommended by the economic analyses, the more cost-efficient is the result, but ultimately the program allocations are subject to policy decisions by the Transportation Commission and CDOT.

Approved program allocations are implemented in program delivery. Asset management encourages consideration of available alternatives in methods to deliver programs,

[8] Models are structured to relate pavement condition and, if included, work zone configuration to user costs of vehicle operation and travel time. Research has also been conducted by the FHWA to relate work zone characteristics to accident frequency. Strategies that reduce user costs (i.e., by improving pavement condition or by reducing the impact of work zones on traffic flow) result effectively in user "benefits." The concepts of user costs and user benefits is thus used interchangeably in this report.

including use of departmental forces, intergovernmental arrangements with other public sector agencies, and outsourcing to the private sector.

Monitoring – System Condition, Performance, and Level of Service

Monitoring of system condition, performance, and level of service provides information for an important feedback loop shown in Figure 11. Periodic inspections to sample system condition, performance measures, and LOS serve the following purposes:

- They confirm whether program investments have improved the transportation system in the manner and degree intended, and provide an objective basis for correlating system condition with customer perceptions of acceptability.

- They update information on the rate of deterioration in condition, performance, and level of service, providing the basis for estimating future program needs and for validating the predictive models used in management systems.

- They identify emerging problems that may necessitate a shift in objectives and targets of future programs.

The process of gauging system condition and providing feedback to set priorities and guidance for future programs that is shown in Figure 11 represents a unified approach between the capital and the maintenance aspects of pavement preservation. This is in contrast to the individual or "silo-based" assessments illustrated in Figure 10. The objective is to promote complete and consistent information on pavement condition, performance, and LOS, so that better decisions can be made for future needs in both capital projects and maintenance, and that the PMS and the MMS can continue to provide consistent recommendations. Working toward greater consistency has the following implications:

- The measures of pavement condition, performance, and LOS used by PMS and MMS should be consistent with one another. This does not mean that each system must use the same set of measures, since they are managing different functions. What it does

imply, however, is that the respective measures should be technically consistent with one another in how they describe a segment of pavement.

- Surveys of condition, performance, and LOS should be coordinated as much as possible. For example, if PMS surveys can provide information for maintenance, this would result in both greater consistency and greater economy in annual inspections. This issue needs to be looked at closely, however, since information needs between the two programs and systems differ, and achieving greater unity will require a cost of modifying one or both of the management systems and their condition or performance measures.

- Achieving greater consistency is also impeded by the different methods used within each system to reflect highway inventory (i.e., road segmentation and attributes like geographic zone). This is a general issue that goes beyond this example with PMS and MMS, and is part of the consideration of information support for asset management that is addressed in a later section.

Monitoring – Program Delivery

This process step in Figure 11 also implies monitoring of program delivery, to ensure that the projects and services agreed to during program development and approval are in fact performed at the route locations and with the methods, materials, and quality intended. A related issue is the degree to which the capital projects and maintenance work actually performed agree with the recommended projects and the LOS that are estimated in the PMS and MMS, respectively. If actual work performed is not in general agreement with system recommendations, the processes in Figures 10 and 11 become internally inconsistent. Maintaining a sense of how the highway system is performing, identifying programs that can address problems cost-effectively, and committing to accountability for results all become more difficult if these processes are internally inconsistent. This issue has arisen in CDOT and is dealt with further below.

Issues Regarding PMS

An advantage of focusing in detail on a specific aspect of asset management, such as the pavement example in Figures 10 and 11, is that practical issues of implementation can be

explored. One such issue has arisen in discussions with CDOT regarding the credibility of PMS recommendations. In brief, the PMS has recently been updated; one of the new capabilities is the adoption of the concept of remaining service life, or RSL, and the use of models to project when RSL is exhausted and pavements may be due for project work. CDOT Region managers have complained that the RSL measure is unstable[9] and that recommended projects do not reflect a realistic mix of the type of work that is actually judged to be needed. PMS managers suggest that the problem of instability in RSL is overstated, and work is now underway to align the predictions of a new system with actual pavement practice.

From a perspective of asset management, the following comments are pertinent regarding the PMS specifically:

1. A credible PMS is critical to successful asset management. CDOT is correct to address problems in its operation and any reluctance to use its results.

2. The instability of RSL estimates in general may be due to problems in data quality from the field inspections, to problems in PMS algorithms that process these data, or a combination of the two. It is not unusual for pavement data to exhibit a high degree of scatter, and there are techniques to reduce scatter (e.g., revisions in sampling and pooling of data). There may also be issues of calibration of measurement equipment, consistency of field data collection practices, or quality assurance in processing of visual data. Algorithms in the PMS itself can be developed to filter unrealistic data or to recognize and attempt to correct for unrealistic trends. CDOT PMS managers appear to be dealing with these issues.

3. Predicted projects may not always agree with projects judged by managers to be the correct approach, since the decision rules in PMS are idealized and simplified

[9] RSL predictions are updated following periodic inspections of pavement condition. The problem of "unstable" RSL refers to values that fluctuate from one update to the next, to the point where it is difficult to have a clear sense of when the pavement segment is actually due for project work.

representations of managers' judgments. A more practical criterion for judging PMS performance is to assess whether the pavement sections identified as candidates for project work are in fact due for projects, based upon field visits. The fact that the updated PMS has only recently been placed in service suggests that a trial period to test and review the decision capabilities of PMS and to align them more closely with good practice as reflected by the collective judgment of CDOT Region managers is worthwhile. CDOT PMS managers appear to be dealing effectively with this issue as well.

At a more general level, PMS credibility is an absolutely necessary condition for good asset management practice, but it alone is not sufficient to ensure better decisions that are the intended result of asset management. The following process improvements should also be considered with respect to the pavement program:

- Pavement sections identified by the PMS as candidates for project work should each be visited by Central Office and Region managers to confirm this assessment, to diagnose any special problems that may exist at the site, and to agree upon the final project recommendation. This procedure helps build credibility and consistency into the program development process.

- As a technical matter, it may help to define the "window" for the upcoming annual program to be longer than 12 months: e.g., 15 or 18 months. In other words, predictions by the PMS of those pavement sections that will exhaust their RSL within a 15-month or 18-month period could be considered as candidates for the next annual program. Other DOTs have found that this longer window mitigates uncertainty in the PMS predictions of RSL, and provides flexibility to program managers in developing programs at stable funding levels over multiple years.

- Monitoring of program delivery should ensure that the projects actually performed conform to those agreed to in program development above. This check is necessary to ensure that the life extension intended to be achieved by these projects will in all likelihood be achieved overall, that a stable program can be maintained from year to

year, and that the asset management objective of minimum long-term cost can be achieved.

Extensions to Other Assets. The example in Figures 10 and 11 focuses on programs affecting one asset class –pavements – to illustrate at a detailed level how asset management recommendations are developed. The pavement example also illustrates how recommendations in several areas often interact with one another: e.g., management systems may need to incorporate more comprehensive or consistent performance measures, and more effective applications of management systems and information may need to be supported by improved business processes. A similar review can be conducted for other asset classes (e.g., bridges) and other Investment Categories (e.g., safety and mobility). It is in this sense that asset management truly becomes a "way of doing business" in an agency.

For example, Figures 12 and 13 compare two different approaches to managing another asset class, bridges. Figure 12 illustrates schematically the current process, in which there is an interaction between bridge capital repairs and maintenance based upon condition state data in CDOT's Pontis® bridge management database. Figure 13 illustrates a more integrated process in which decisions on capital-maintenance tradeoffs are made based upon an overall view of bridge needs and performance-based criteria such as benefit-cost. Data from both the BMS and the MMS would be available for display on a GIS map, together with information on pavements and other asset classes or programs.

Extensions to Other Programs. Additional examples of how to implement asset management principles at a process level can be developed by considering other types of programs. Figures 14 and 15 show how the decision processes for the Safety Investment Category can be structured to be consistent with principles of good asset management practice. In contrast with the pavement and bridge examples, which compare "current" to "improved" processes, this example for safety illustrates how several elements of a program can be brought together within a single decision-making framework.

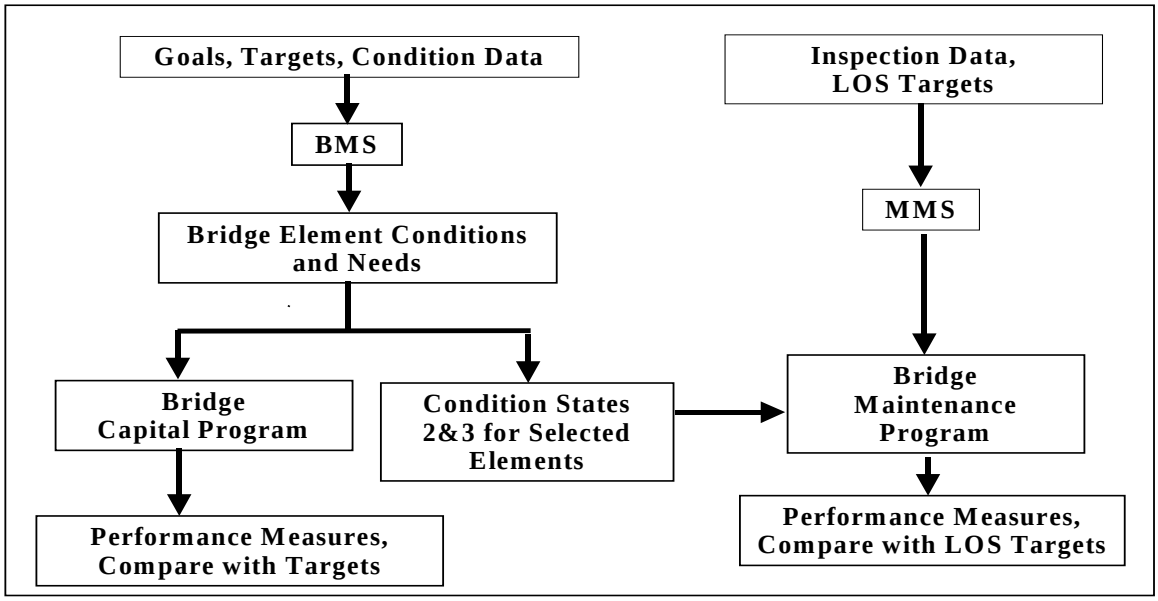

Figure 12. Current Approach to Bridge Program Development and Implementation

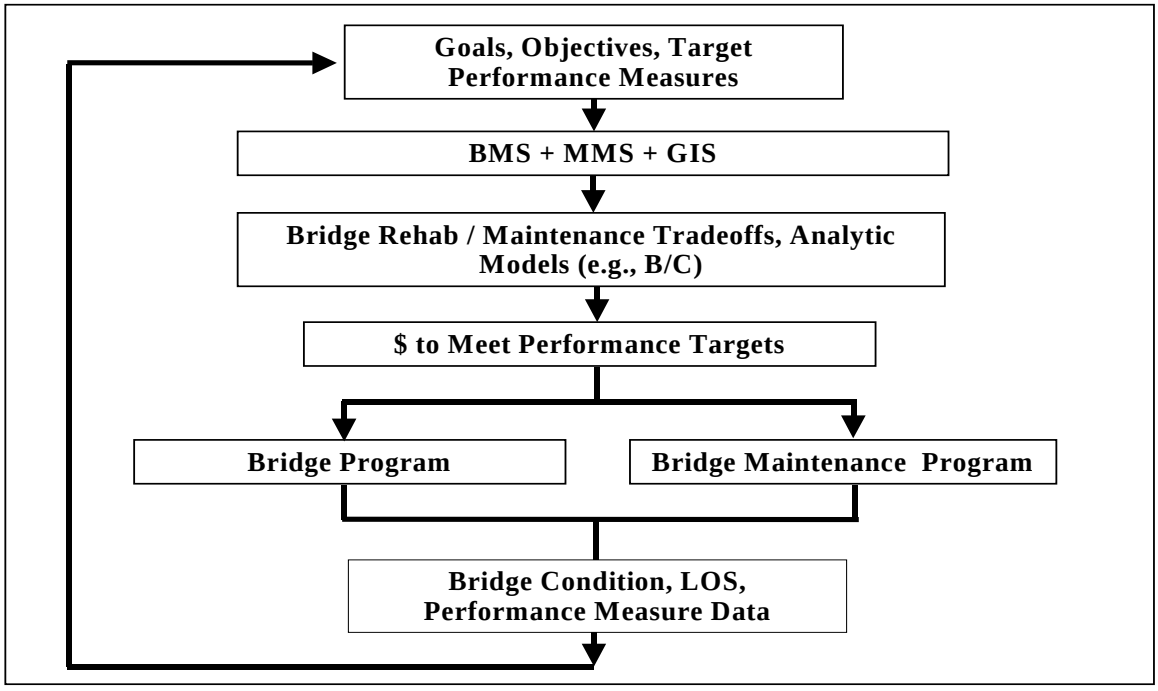

Figure 13. Improved Approach to Bridge Program Development and Implementation

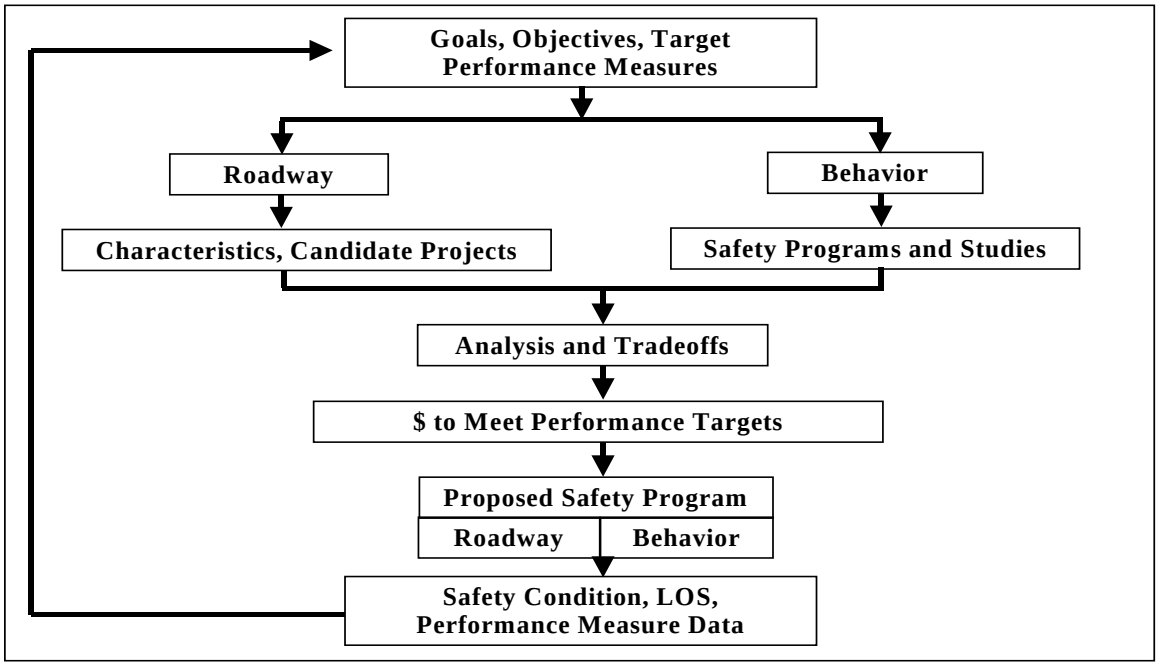

Figure 14. Overall Safety Investment Category

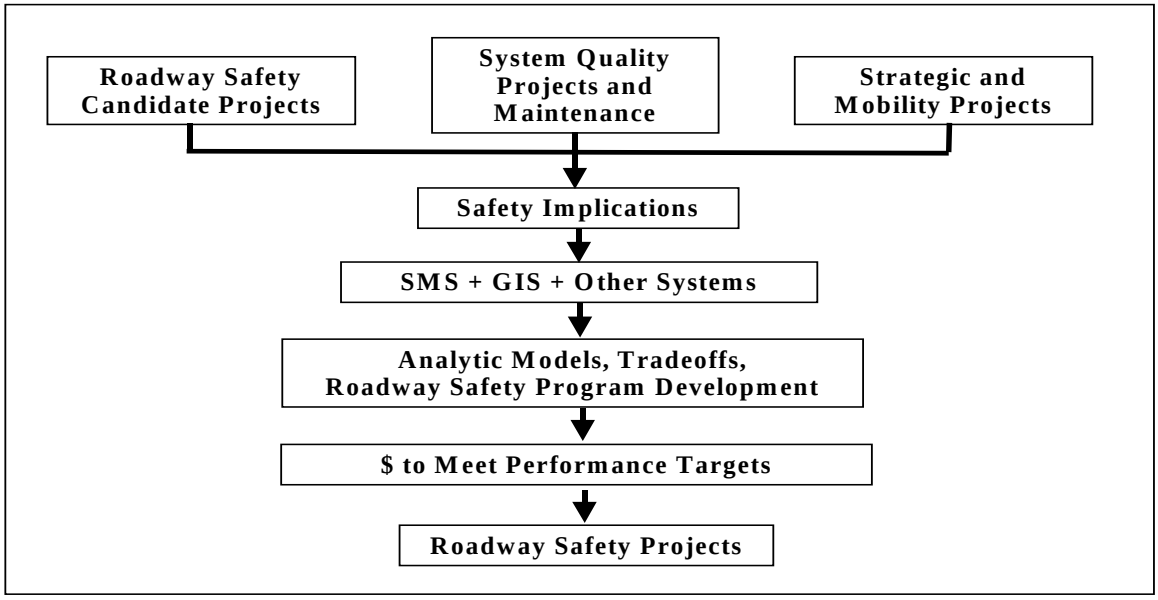

Figure 15. Roadway Component of Safety

CDOT concentrates its safety efforts in two major areas: (a) a roadway component, which funds safety projects in the physical highway infrastructure; and (b) programs to reduce improper driver behavior. Figure 14 depicts the overall safety program, which illustrates these two program components. Since the behavior component affects roadway operations, it too can be considered within the broad definition of asset management. In this context, the two program components can be managed according to the ideas and principles discussed in Section 1.0 and developed further in the examples given in this section. For example:

- The roadway and the behavior programs can each be developed by considering alternative projects and actions to accomplish the objectives in each area respectively;
- Specific objectives in each program component can be established in terms of target values of performance measures, which also contribute a basis for prioritization;
- Tradeoffs between Safety roadway and behavior components can be evaluated in terms of forecast improvements in performance; similarly, tradeoffs can be evaluated between Safety and other Investment Categories;
- The most effective combination of roadway and behavior program components can be recommended for the overall Safety Investment Category; and
- System and program delivery monitoring can be applied to assess the performance of each program, allowing for contributing factors from other sources (refer to following discussion).

While the Safety Investment Category serves to fund specific programs and projects that directly reduce accident risk and cost, safety improvements can also result from other Investment Categories. Figure 15 illustrates this for the roadway component where, in addition to candidate projects being considered for Safety, one can also account for the safety implications of proposed work in other Investment Categories. From an asset management perspective, this process is enabled by a set of safety-related performance measures that are consistent across the Investment Categories. These performance

measures are defined in addition to primary measures that may be needed to evaluate projects and services in System Quality, Mobility, and the Strategic Projects. Based upon this overarching view of proposed system performance regarding safety, a set of roadway safety projects can be recommended as part of the Safety Investment Category process in Figure 14.

4.3 Development of the Asset Management Plan

To deal with the breadth and complexity of asset management illustrated in Section 4.2, we have applied the guidelines now being developed in NCHRP Project 20-24(11) (summarized in Section 1.0) to the CDOT business processes and information technology capabilities that were reviewed in Section 2.0. Experience from other DOTs (Section 3.0) has also suggested new approaches.

The resulting plan is organized as a series of objectives and tasks in four key areas: policy and institutional factors, planning and program development, program delivery, and information and analytic tools. For each objective or task the plan identifies the responsible CDOT organizational unit, the intended benefit, the role of the Transportation Commission and involvement of other regional or local agencies as applicable, the timeframe in which the recommendation is recommended for implementation, and the cost if applicable. Timeframes have been specified as follows:

- Near-term – 2001-2001;
- Mid-term – 2003-2004; and
- Long-term – 2005 and beyond.

To keep the recommended program manageable, we have focused on descriptions of key tasks. As the discussion of Section 4.2 indicates, however, each task is likely to entail a number of detailed issues and interactions with other tasks that will need to be resolved. To provide continuing guidance in this effort and high-level leadership of the several CDOT organizational units that will necessarily be involved in plan implementation, we have

recommended the formation of a departmental task force under the leadership of the Deputy director.

Costs have been provided as estimated budget amounts[10] for those tasks for which it appears likely that a consultant project may be defined. Costs have not been provided for tasks likely to be accomplished by departmental personnel, although a commitment of some time is obviously implied.[11] In many cases, these recommended tasks represent work that department staff would have accomplished even in the absence of asset management recommendations. What asset management has provided is a perspective on certain objectives that the tasks should accomplish. In this way, asset management becomes ingrained as a "way of doing business" within the department.

The asset management plan is summarized in Tables B through E.

[10] By "budget amount" is meant the total expenditures that CDOT may wish to plan for to fund one or more projects. For example, the recommendation of analytic tool development at an estimated cost of $1,000,000 may entail, say, up to four individual projects at $250,000 each. In some cases the full recommended amount may not be needed (e.g., if appropriate research is sponsored by others).

[11] Additional costs may need to be estimated if the decision is made to outsource some of this work.

Table B. Asset Management Plan – Policy and Institutional Factors

Objective *CDOT Unit Responsible*	**Intended Benefit**	**Task**	**Timing and Cost**
A. Designate a departmental task force under the Deputy Director to guide implementation of the asset management plan. *Director*	Establish executive buy-in; provide leadership; coordinate efforts of multiple department units.	1. Designate the task force, building upon the experience of the Project Panel for Asset Management Plan development.	Near-term
B. Complete and refine Investment Category goals, targets, and performance measures *DTD*	More comprehensive understanding of transportation impacts of total program; ability to apply Investment Categories to program development and tradeoff analyses	1. Complete definition of statewide goals, targets, and performance measures for all programs. 2. Discuss the completed approach with local and regional planning agencies.	Near-term Near-term
C. Fold the performance measurement of all programs, including future strategic ("7th pot") projects, within the Mobility, Safety, and System Quality Categories *DTD*	Ability to track and compare the results of all projects in a consistent manner	1. Apply established performance measures to identify impacts of all projects, including strategic projects. 2. Implement procedures on a trial basis, assess results, discuss with Transportation Commission, and finalize.	Near-term Near-term

Table B. Asset Management Plan – Policy and Institutional Factors (continued)

Objective *CDOT Unit Responsible*	**Intended Benefit**	**Task**	**Timing and Cost**
D. Define state interest in non-state-owned infrastructure. *EMT*	Enhanced systemwide decisions; wider alternatives, potential cost savings for solutions to state transportation problems	1. Identify and categorize non-state-owned assets in which CDOT has an interest.	Mid-term
		2. Review potential investment policies with Transportation Commission	Mid-term
E. Improve public and internal understanding and support of asset management techniques. *Deputy Director*	More informed and committed staff; increased public awareness and support	1. Hold periodic departmental workshops to discuss asset management and its implications for department activities.	Near-term
		2. Develop and distribute public information describing asset management and its importance.	Near-term $75,000
		3. Track public perceptions of, and satisfaction with, asset management performance through customer surveys.	Mid-term

Table C. Asset Management Plan – Planning and Programming Factors

Objective *CDOT Unit Responsible*	**Intended Benefit**	**Task**	**Timing and Cost**
A. Implement tiered classification of transportation assets. *DTD*	Provide rational basis for standards, levels of service, interpretation of performance throughout system; more efficient and cost-effective asset management.	1. Implement recommended tiered system on a trial basis in cooperation with local and regional agencies. 2. Implement final set within planning and programming procedures and management and information systems.	Mid-term Long-term $500,000
B. Develop more complete scope and cost information for STIP projects (coordinate with Program Delivery) *OFMB*	Stronger basis for program delivery and accountability.	1. Work with Regions to define a process and information needs. 2. Implement by 2004.	Mid-term, $250,000 Mid-term
C. Strengthen application of performance measures. Deputy Director, Chief Engineer, DTD, Asset Managers, Maintenance & Operations	Increased ability to track the success of programs in terms of defined goals and objectives both at the agency and program levels Greater understanding of how various funding levels will impact system performance	1. Develop consistent measures across Investment Categories and programs serving common goals (e.g., safety, pavement/ maintenance, bridge/ maintenance) 2. Develop specialized tools for tradeoff analyses and promote greater integration among management system and data	Near-term Near- to Mid-term, $1,000,000

Table C. Asset Management Plan – Planning and Programming Factors (continued)

Objective *CDOT Unit Responsible*	**Intended Benefit**	**Task**	**Timing and Cost**
		3. Develop or adapt applications to predict customer impacts in terms of user costs.	Long-term, $250,000
D. Review over time those program allocations based on formulas to ensure consistency with performance-based asset management *Deputy Director*	Objective understanding of basis for allocation of resources	1. Perform the following: • Identify program components subject to "fixed" or "formula" distributions. • Analyze implications across Regions and TPRs, comparing formula distributions versus implied distributions based upon performance measures. • Discuss comparison with Transportation Commission, CDOT managers, local and regional agencies. • Implement recommended changes.	Long-term, $250,000

Table D. Asset Management Plan – Program Delivery Factors

Objective *CDOT Unit Responsible*	**Intended Benefit**	**Task**	**Timing and Cost**
A. Strengthen tracking of program delivery and major project changes (coordinate with Planning and Programming). *Deputy Director*	Identify opportunities for risk and cost reduction; improve accountability to constituencies	1. Develop program tracking methodology and system based upon more complete initial cost and scope estimates. 2. Establish a program review team to meet periodically to review and approve major changes in scope, time, and cost.	Mid-term, $350,000 Mid-term
B. Ensure consistency of accomplishments with program estimates of PMS, BMS, and MMS *Chief Engineer*	Maintain program consistency; ensure full value received for funds expended; maintain stable network condition at least life-cycle cost	1. Reinforce procedures to define projects by employing information from management systems. 2. Expand project delivery reports to confirm specific project treatments applied, or reasons for deviation	Mid-term Mid-term

Table E. Asset Management Plan – Information and Analytic Factors

Objective *CDOT Unit Responsible*	**Intended Benefit**	**Task**	**Timing and Cost**
A. Meet end-user needs for complete, accurate, timely information. *Chief Engineer*	Make better, smarter use of existing system capabilities.	1. Conduct QA/QC checks to achieve reliable, credible management system operation and predictions	Near-term
		2. Schedule training of asset management staff to become more familiar with full range of PMS, BMS, MMS capabilities and to make better use of existing system capabilities	Near-term, $50,000
		3. Fill analytic gaps with simple, quick, economical tools.	Near- to Mid-term, $200,000
B. Enhance Information Technology (IT) support for asset management in CDOT. *Deputy Director*	Ensure critical support and effective planning for information needs now and in the future.	1. Reconstitute the ITRT to provide high-level guidance for asset management.	Near-term
		2. Charge the ITRT to develop and implement an IT plan for asset management (e.g., to guide system integration and new system development)	Near-term

Table E. Asset Management Plan – Information and Analytic Factors (continued)

Objective *CDOT Unit Responsible*	**Intended Benefit**	**Task**	**Timing and Cost**
C. Integrate asset management system data on CDOT's GIS. *ITRT*	Promote better communication; better understanding of strategic and corridor situations	1. Details to be developed in IT plan, including: • Classification of assets in a tiered structure; • Integrated condition and performance measures, referencing systems, data sources; • Program and project information to be displayed on GIS; • System capabilities: displays, queries, reports.	Mid- to Long-term; must be coordinated with other GIS objectives; potential cost is at least several million dollars, not exclusively for asset mgmt.

4.4 Implementation Plan for Near-Term Items

Several items in Tables B through E are scheduled for near-term accomplishment. Many of these items are organizational and procedural in nature, build upon the considerable work that CDOT already has done to promote better asset management, and entail little or no cost. As a general rule, most of the cost items in the Asset Management Plan recommendations relate to information technology, training, and public information, and in these areas the proposed budgets can be adjusted to reflect current assessments of needs and availability of research results sponsored by others. An elaboration of the near-term objectives and suggestions for implementation follows.

CDOT Task Force. The first task recommended for accomplishment (Table B, Task A.1) is for CDOT to form a Task Force to oversee implementation of the Asset Management Plan. The Task Force will assume the guiding role that has to date been exercised by the Project Panel for this study. Early formation of the Task Force under the leadership of the CDOT Deputy Director and breadth of representation in its membership will help satisfy a number of objectives:

- To provide high-level leadership and demonstrate buy-in by Departmental executives and managers that is visible and meaningful to CDOT staff and outside stakeholders;
- To translate recommendations into actions quickly, maintain a long-term perspective on objectives and tasks, periodically assess planned versus actual accomplishments, and perform mid-course adjustments when needed;
- To coordinate actions across Departmental organizational units, and guide development and implementation of integrated practices where needed (e.g., data collection and processing, evolution of GIS capabilities);
- To view the Department's activities and decision processes from a strategic as well as tactical perspective in applying asset management principles; and
- To provide a credible and effective organizational basis for communication of plans and accomplishments to the Transportation Commission, and to be able to implement the Commission's recommendations regarding asset management efficiently and effectively.

The Task Force provides a focal point for leadership and coordination that is needed by a topic as broad as that of asset management. In performing its responsibilities the Task Force should heed the Transportation Commission's concerns that asset management not become simply another program, and the Task Force another layer of bureaucracy.[12] The premise that asset management is "a way of doing business" must be maintained by the

[12] Transportation Commission workshop on this study's recommendations, March 14, 2001.

Task Force in its consideration of a wide range of business process and information technology issues. A separate Task Force is recommended in lieu of enlarging the responsibilities of existing CDOT committees or teams so as to be able to consider, at each meeting, a number of issues and agenda items related specifically to asset management, and to devote sufficient time to each.

Complete Investment Category Structure for Full Operational Use. CDOT's Investment Category structure is the foundation of the Asset Management Plan. Its completion for full operational use entails several items discussed for near-term accomplishment in Table B, Tasks B.1, B.2, C.1 and C.2, and Table C, Tasks C.1 and C.2:

- Complete elements of the structure: i.e., performance measures, goals, specific numerical targets, and analytic tools (e.g., for prioritization and tradeoff analyses, on a final or interim basis);

- Ensure consistency and effectiveness among performance measures to be able to conduct the types of analyses discussed in this Plan: e.g., understanding the costs and the consequences of projects, assessing tradeoffs in funding between Investment Categories and between programs, and evaluating the consequences of several Investment Categories jointly (e.g., with regard to safety);

- Fold performance measure targets and accomplishments associated with Strategic ("Seventh Pot") projects into the Mobility, System Quality, and Safety Investment Categories; and

- Discuss key elements of the updated Investment Category process with the Transportation Commission and regional and local planning organizations, and refine as needed.

The Investment Category structure will likely always be in continual evolution and advancement as new transportation needs and solutions are identified, and targets, performance measures, and associated analytic tools adjusted accordingly. This set of tasks therefore refers to bringing the elements of the Investment Category structure to a point of

development where the structure functions as intended, even if some of the models or performance measures are still tentative. It also refers to the institution of business processes in planning, programming, and system monitoring that support and make use of the Investment Category structure in decision-making and in communicating recommendations and results to the Transportation Commission.

Communicate "What Is Asset Management." Asset management is often difficult to understand, for a number of reasons:

- It is broadly applicable to many departmental units and organizational levels;
- It is a "way of doing business" rather than a specific program or product; and
- Typically it will be tailored by different DOTs to meet different situations and needs, thus presenting a different "look" at each location.

Asset management may therefore come across, variously, as an abstract concept or with a certain cast – e.g., an effort perhaps focused on high-level policy planning, or a "magic bullet" information technology solution. DOT managers and staff in field offices may perceive it differently from those in the central office, and different organizational units may associate it more with their particular activities rather than the broader picture that asset management tries to address. Vagueness and possible misconceptions of asset management can be countered with an effective communication program. Such a program can not only de-mystify asset management and eliminate confusion as to how it relates to other departmental initiatives, but more importantly it can help departmental units and organizational levels understand how asset management influences and can improve the effectiveness of their daily work.

The Asset Management Plan therefore recommends a communications program for CDOT employees and for outside stakeholders to be undertaken in the near-term (Table B, Tasks E.1 and E.2). The purpose is to clarify what asset management is, what are its benefits, and how its strategic objectives translate into more effective tactical decisions. The Plan recommends a series of periodic workshops for CDOT employees to discuss

aspects of asset management and the current status of CDOT implementation. A budget of $75,000 has been included for production and distribution of pamphlets or similar materials to outside stakeholders, which can be coordinated with inclusion of this material in CDOT's web site. The information in this report can be used as a basis for development of workshops and written materials, coupled with additional examples from various CDOT functions. Michigan DOT already has a package of informational sheets on its activities and capabilities in asset management (refer to Section 3.0). A communications component has been added to NCHRP Project 20-24(11) to assist AASHTO member agencies in explaining the objectives, content, and benefits of asset management generally.

Information Technology Support of Asset Management. Information systems and analytic tools are practical necessities for good transportation asset management in a modern DOT. Management systems provide needed information in a number of areas related to good asset management:

- An inventory of assets to be maintained, with information on condition and performance;
- Identification of needed work to improve structural or operational performance, based upon explicit decision rules or criteria;
- A relationship between target condition levels, performance levels, or levels of service, and the cost to provide these levels to customers;
- An accounting for changes in assumptions regarding, for example, system usage and topographic or climatic effects on performance and costs;
- Estimates of the consequences of budget constraints and specified activity priorities among activities; and
- Capability to test and compare scenarios: i.e., the implications of particular assumptions (such as regarding forecast traffic usage or revenue and funding levels), or changes in decision rules and criteria.

The Asset Management Plan includes a number of recommendations to enhance the role of existing management systems and databases for asset management, and to develop new analytic tools to fill gaps as appropriate. A commentary on the relevant near-term tasks is as follows:

Reconstitution of ITRT

Just as asset management requires breadth in addressing business and decision processes, so too does it entail a department-wide view of information capabilities. The Asset Management Plan recommends that the existing ITRT be reconstituted to provide high-level expertise regarding needed systems and data capabilities and ways to attain them (Table E, Task B.1). While the responsibilities of this reconstituted ITRT may extend beyond the scope of asset management, a sufficiently broad and high-level membership is needed to comprehend fully the requirements of asset management as an integral part of CDOT's activities, and to develop and implement solutions at both strategic and tactical levels. It may be helpful for the proposed CDOT Task Force on Asset Management to be given a role in identifying candidate members of the new ITRT, and the ITRT should be charged with a reporting responsibility to the Task Force, among other CDOT management groups. The ITRT should be viewed as both a body representing internal CDOT "customers" of asset management information, and a technical advisory board on systems and data issues to the Task Force.

IT Strategic Plan

To enable the ITRT to articulate strategic directions for supporting asset management, the Asset Management Plan recommends that the ITRT develop and implement an Information Technology Plan (Table E, Task B.2). The objective of this IT Plan is to guide system architecture, including issues of system integration, updating of legacy systems, and new system development in a way that supports asset management needs throughout the Department.

- This Plan effectively updates work that CDOT has had underway (e.g., in data warehouse development) since about 1990, but fills a critical gap regarding decision support and related policy and technical information for asset management specifically.

- The IT Plan should address the several asset management systems now in use (e.g., PMS, BMS, MMS), other infrastructure-related systems proposed for development, and other existing or planned systems providing relevant information important to asset management (e.g., financial management and accounting).

- The IT Plan should consider a range of possible solutions to identified asset management needs, ranging from relatively simple analytic tools (e.g., spreadsheets, or modest database or program applications) to fully developed management information or decision-support systems.

- The IT Plan should explicitly consider how information and analytic capabilities can be integrated most effectively, including use of CDOT's GIS. These discussions will no doubt extend beyond asset management, but asset management must be an explicit consideration in the recommendation of a long-term strategy and specific initial steps.

- The IT Plan should document the systems aspects of CDOT's compliance with GASB 34 standards and evolution of methods and information used in financial reporting.

- The IT Plan should be updated at least every three years to account for changing needs, advances in technology, updates of budget assumptions, and experience with capabilities developed to date.

Credibility of Asset Management Systems

CDOT's PMS, BMS, and MMS have recently been updated or are due for updated versions shortly. These updates may require a trial period to resolve issues in data integrity and accuracy of predictions. Since these management systems are critical to the performance of good asset management overall, the Asset Management Plan identifies a specific task in

which various departmental units should work to establish the credibility and usefulness of these systems (Table E, Task A.1). This task entails the following:

- The basic objective should be to work toward the credibility of these systems so that they can be reliably and effectively used in program development, system monitoring, scenario testing, tradeoff analyses, and other analyses needed in asset management. As a practical matter, good asset management depends upon working applications in PMS, BMS, and MMS. Furthermore, CDOT's intention to apply the "modified approach" for financial reporting of infrastructure, as allowed by GASB Statement 34, essentially requires that a PMS, BMS, and MMS be employed.

- The bar should not be set unrealistically high for establishing the credibility of these systems. Their role is to provide reasonable estimates of deficiencies, their locations, and recommended types of projects. These estimates should, however, be confirmed by managers in the field prior to recommending projects.

- Relevant business processes should reinforce the use of management system information. For example, project and program development should call for analyses of current deficiencies as part of the normal asset management cycle, and explicit review of system results as part of project identification and selection, proposal of maintenance levels of service, and recommendation of annual programs and budgets.

- Monitoring of program delivery should confirm that the recommended projects and maintenance levels of service, which were developed with the use of management system results, have actually been performed in the manner, at the cost, and with the outcomes as originally forecast. This check is useful not only for good asset management and for long-term consistency between management system data and actual field conditions, but also for validation of information on planned versus intended condition levels and expenditures as required by the modified approach in GASB Statement 34. Significant deviations can identify potential problem areas, and guide updates of system information, assumptions, decision rules, and models if needed.

Training to Use Existing Capabilities Better

Surveys of management system use nationwide indicate that the capabilities of current applications such as PMS and BMS are typically underutilized, particularly for policy decisions by higher levels of management. The Asset Management Plan therefore recommends a training program to acquaint CDOT asset managers with these existing system capabilities (Table E, Task A.2), and how they can be used in conjunction with the analyses anticipated by the Investment Category structure. The benefit of this training will be better and smarter use of existing system capabilities at little additional time or cost.

A primary example of underutilized system capabilities is in scenario testing, particularly to investigate the relationship between projected annual budget levels and resulting network conditions. The following example is developed using the Pontis® 4.0 BMS, although analogous results can be developed for PMS and levels of service in MMS.[13] The example assumes a bridge inventory in which the age (or current condition) of bridges is assumed to be distributed uniformly.

Three budget scenarios are investigated. Each scenario tests a particular annual expenditure level to preserve the bridge network through a 10-year analysis period. Figure 16 plots the condition of the bridge network versus time in years. The network-average bridge condition is gauged by the percent of bridges with Health Index (HI, a measure of bridge structural condition) greater than 75 on a scale from zero (poor) to 100 (excellent). Other measures of condition, such as sufficiency rating, can also be used. The budget levels correspond to the following projected annual expenditures:

[13] The bridge management example is developed for a sample network of 500 bridges, not the CDOT bridge inventory. The example is illustrative of the types of trends that can be expected for any inventory and set of bridge activities and costs.

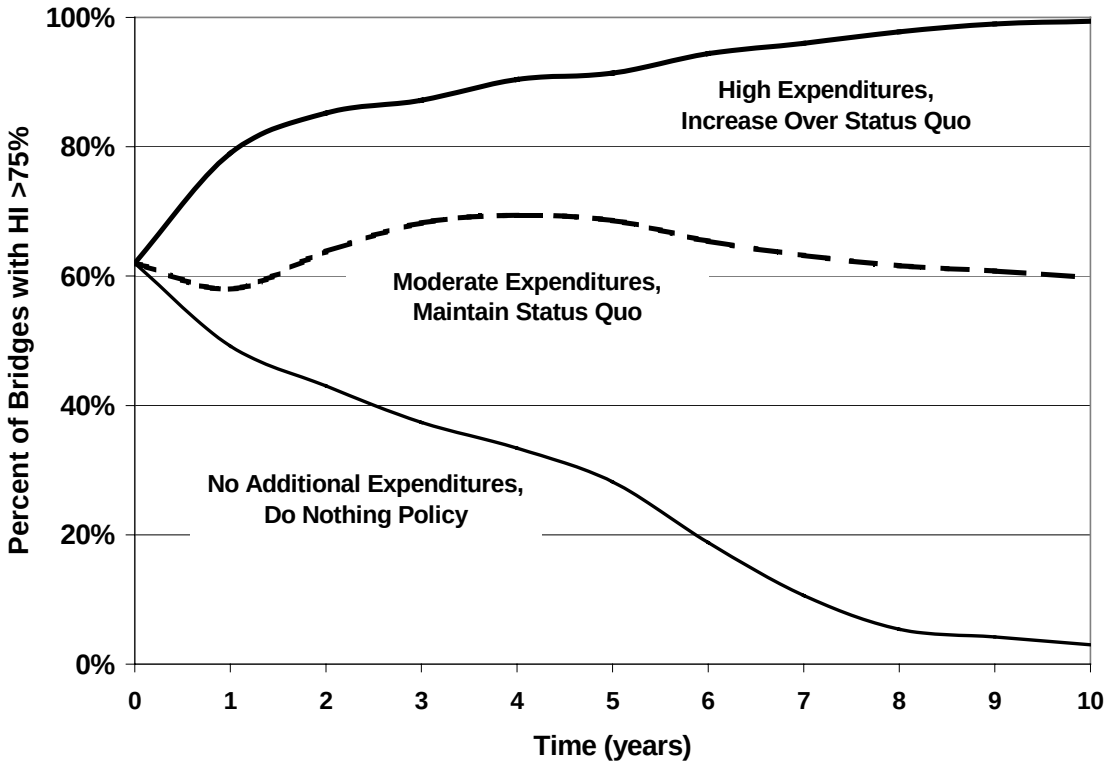

Figure 16. Example of Budget Scenarios and Effects on Network Condition

- A relatively high annual expenditure, which results in improvement of bridge network condition through the 10-year period. This case is illustrated by the top curve in Figure 16.

- A moderate annual expenditure, which is sufficient to maintain the status quo in network bridge condition through the analysis period. This case is illustrated by the middle curve in Figure 16.

- No annual expenditure, representing a "do-nothing" policy, which results in a decline of network bridge condition through the analysis period. This case is illustrated by the bottom curve in Figure 16.

The three scenarios each result in a markedly different result at the end of the 10-year analysis period, and together define an envelope delimiting a range of options in funding bridge preservation. It is possible to plot the condition level at the end of 10 years, as

indicated in Figure 17, versus the corresponding annual budget or expenditure level. The result is the relationship between condition level and needed expenditure as shown in Figure 18. The inverse of this function is given in Figure 19.

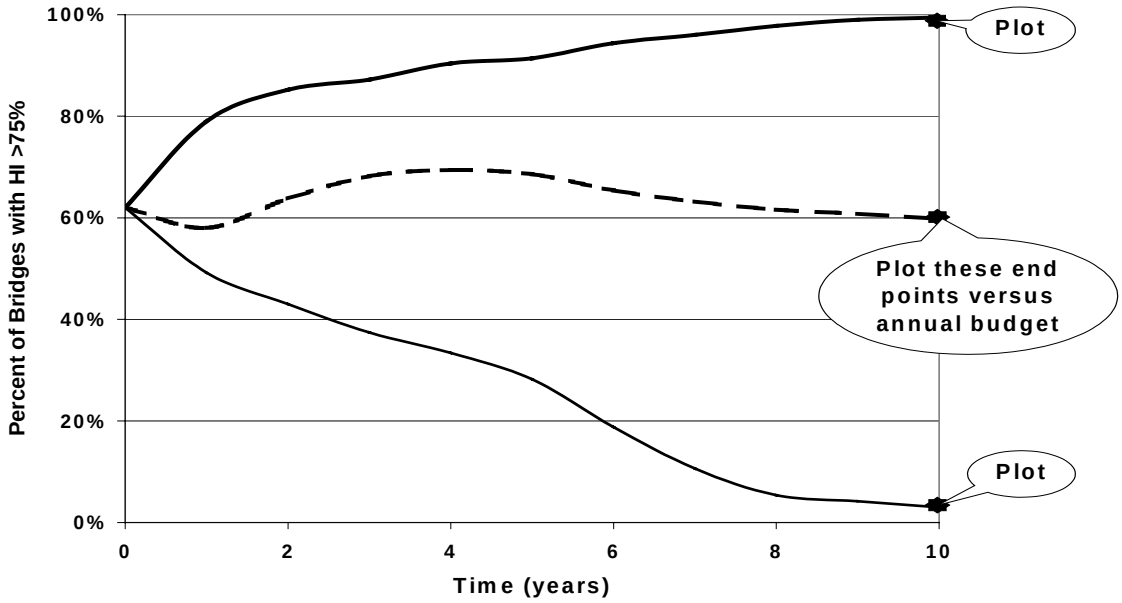

Figure 17. Identification of Points to be Plotted to Relate Condition and Needed Expenditure

Figures 18 and 19 capture the tradeoff between constant expenditure level and resulting long-term condition. This relationship can be used directly as a guide identifying the expenditure level to meet a specified target condition level. It can also be used to explore long-term trends in network condition for different possible funding scenarios, and to discuss these with policy-makers in a proactive way. While this example focuses on bridges, other types of management systems also employ a scenario-testing or a similar capability. These analyses have significant benefit for asset management generally. For example, the curves in Figures 18 and 19 can be used for a several purposes, including program budget recommendations, impact analyses of changes in funding levels, and tradeoff analyses with other programs. They also form the basis for relating needed expenditures to intended condition level in complying with the modified approach in GASB Statement 34. These curves illustrate one potential objective of CDOT staff training.

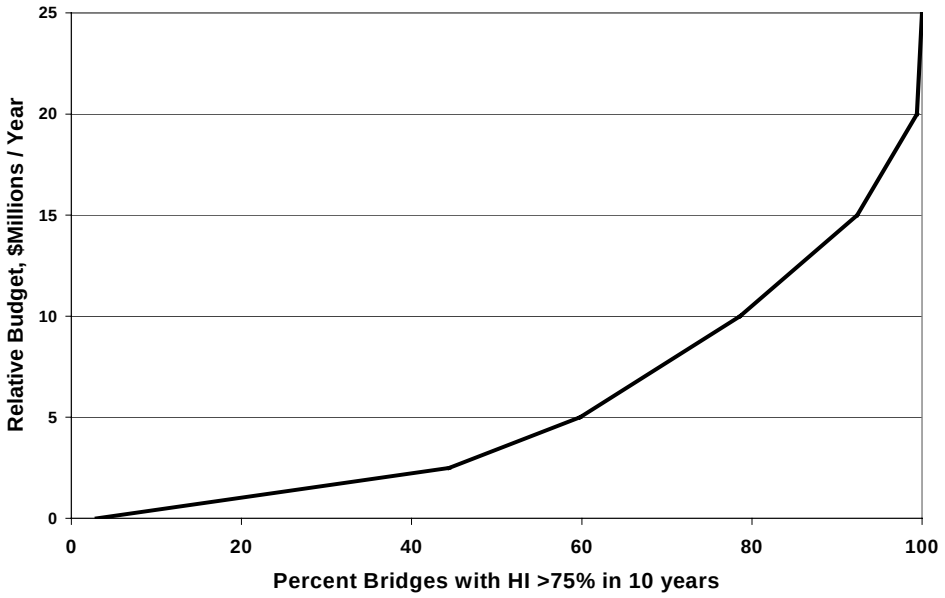

Figure 18. Resulting Relationship Between Network Condition and Needed Expenditure

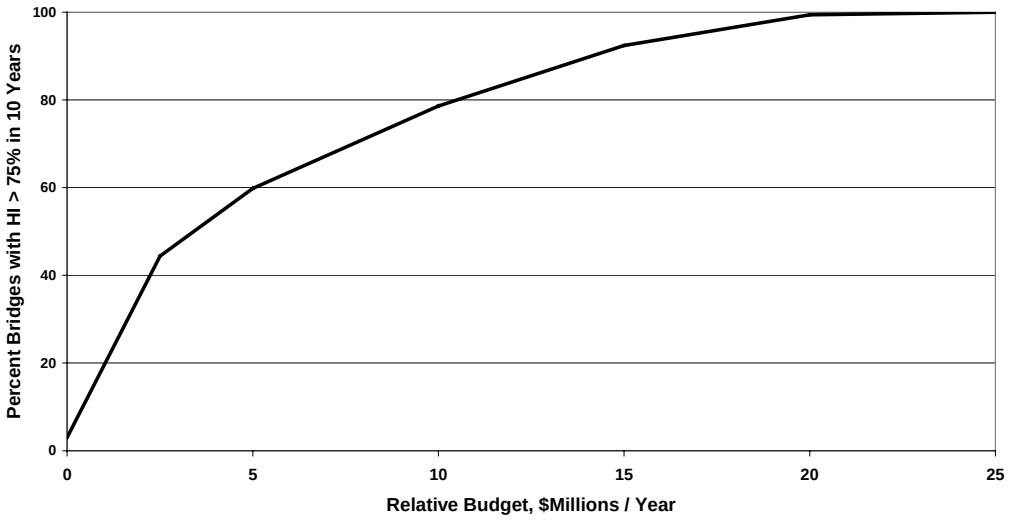

Figure 19. Resulting Relationship Between Annual Expenditure and Network Condition

Development of Analytic Tools

While existing management systems support many of the computational needs of the Investment Category structure, there are specialized analyses that current systems do not address. These gaps exist, for example, in economic analyses of preferred strategies that cut across programs (e.g., capital-maintenance tradeoffs), and comparative analyses of cost and performance tradeoffs between Investment Categories or between programs. The Asset Management Plan envisions filling these gaps initially with simple, economical tools in lieu of full management system design and development (Table E, Task A.3). Example applications that can be met by these tools include performance-based budgeting, tradeoff analyses, estimates of user costs and benefits, and provision and formatting of information for executive-level decisions.

These analytic tools can be developed, for example, as spreadsheet workbooks or compact programs or database applications. Such tools can exchange information electronically with other systems if required. Their advantage is that they entail relatively low-cost and low-risk design, production, and implementation, but provide the additional functionality needed to gain the full advantage of the Investment Category structure. They can also be used to strengthen existing legacy systems by updating certain calculations. They may remain in use indefinitely in conjunction with existing legacy systems, or, when legacy systems are due to be updated, they can provide the conceptual and logical basis for designing their respective computations into the planned replacement system.

4.5 Implementation Roles of the EMT and the Transportation Commission

The CDOT EMT and the Transportation Commission each can contribute to the implementation of transportation asset management. The roles that can be played by the EMT include the following:

- Providing an example of executive leadership and buy-in to the application of transportation asset management in CDOT;

- Promoting the integration of several aspects of asset management, ensuring that policy formulation, business processes, and application of information and analytic tools are consistent with one another; and

- Ensuring that appropriate asset management techniques are implemented at each organizational level within CDOT, promoting better decisions based on better information, improved stewardship of transportation infrastructure, and more cost-effective service to customers.

The contributions that can be made by the Transportation Commission to asset management implementation include the following:

- To interpret and exercise its functions and responsibilities in the context of transportation asset management, such as in the following areas:
  - Basing relevant policy formulation upon system information;
  - Considering a range of options in each Investment Category;
  - Evaluating tradeoffs among Investment Categories or among Programs within an Investment Category;
  - Reviewing program delivery; and
  - Reviewing system performance in light of past investment decisions.
- To encourage CDOT implementation of asset management recommendations, integrating improved business and decision processes with better information, analyses, and reporting.

5.0 Tiering of the Transportation Assets

This section presents the recommendations for tiering of the highway system elements of the Colorado Department of Transportation's (CDOT) infrastructure assets – both state-owned and of state interest. The tiering or classification of other modal elements of the state transportation system – aviation, railroads, transit, and bicycles – will be incorporated "as is" into this research effort using the classification and tiering already developed. This focus is on the tiering of the highway infrastructure because that is the asset type for which there appears to be most interest and need for a modified approach to classification and tiering. It is also the asset category for which CDOT invests the lion's share of its nearly $1 billion annual budget. The tiering recommendations presented here are for use as the common tiering structure across the principal investment categories – System Quality, Safety, Mobility, and Strategic Projects. Additional tiering that may be beneficial specifically within an individual investment category is not covered here.

This recommended tiering structure is the second of the two major products of this research project. The first and foremost product is the Asset Management Plan presented in Section 4.0. While that concept asset management plan can be advanced without also introducing the concept of tiering, tiering can provide a useful perspective regarding the transportation assets that can assist in the understanding of customer needs and expectations, target-setting for results, forecasting, monitoring and reporting, and investment decision-making.

The format of this section is as follows:

- Tiering – what is it and why do it;
- Existing/recent applications of tiering at CDOT
- Need for additional tiering for the highway element of the transportation system;
- Results of outreach and research into other states; and

- Recommended tiering structure concept for the CDOT highway element of the transportation system.

5.1 Introduction to Tiering

Tiering is a classification or categorization scheme for the transportation system assets, usually within a hierarchical or prioritized structure. One example of tiering that is currently widely used by the Department is that of the three-tiered highway classification: Interstate, National Highway System (NHS) other than Interstate, and "Other" non-NHS roadways. The basic purpose of tiering is to assist managers and decision-makers in making better investments to serve customers. Tiering allows decision-makers to recognize the different customer needs and expectations and thus potentially different types and levels of importance and investments for different tiers of the transportation system. In the CDOT Pavement Program, for example, the desired pavement quality or condition target varies by tier, with the highest (best) target established for Interstate, followed by NHS and then "Other." The Transportation Commission has established a systemwide pavement quality objective of 85 percent "good or fair" for Interstate roadways, 70 percent good or fair for NHS other than Interstate, and 55 percent good or fair for Other roadways. The blended target pavement condition for the entire CDOT roadway system is 60 percent good or fair after accounting for the number of lane-miles in each tier. The types of pavement restoration efforts and the levels of expenditures are thus varied across roadway tiers to achieve these Commission-established outcomes. This tiered classification scheme based on roadway categories is currently used throughout the System Quality Program of CDOT's Transportation Investment Strategy, the framework for the Department's outcome-based budgeting process. This tiered structure is based on the development by the Federal Highway Administration (FHWA) of the National Highway System, or NHS, and was created from a national perspective on the state's roadways. Figure 20 shows a map of the CDOT 9,200 centerline-mile highway system with the three highway tiers identified.

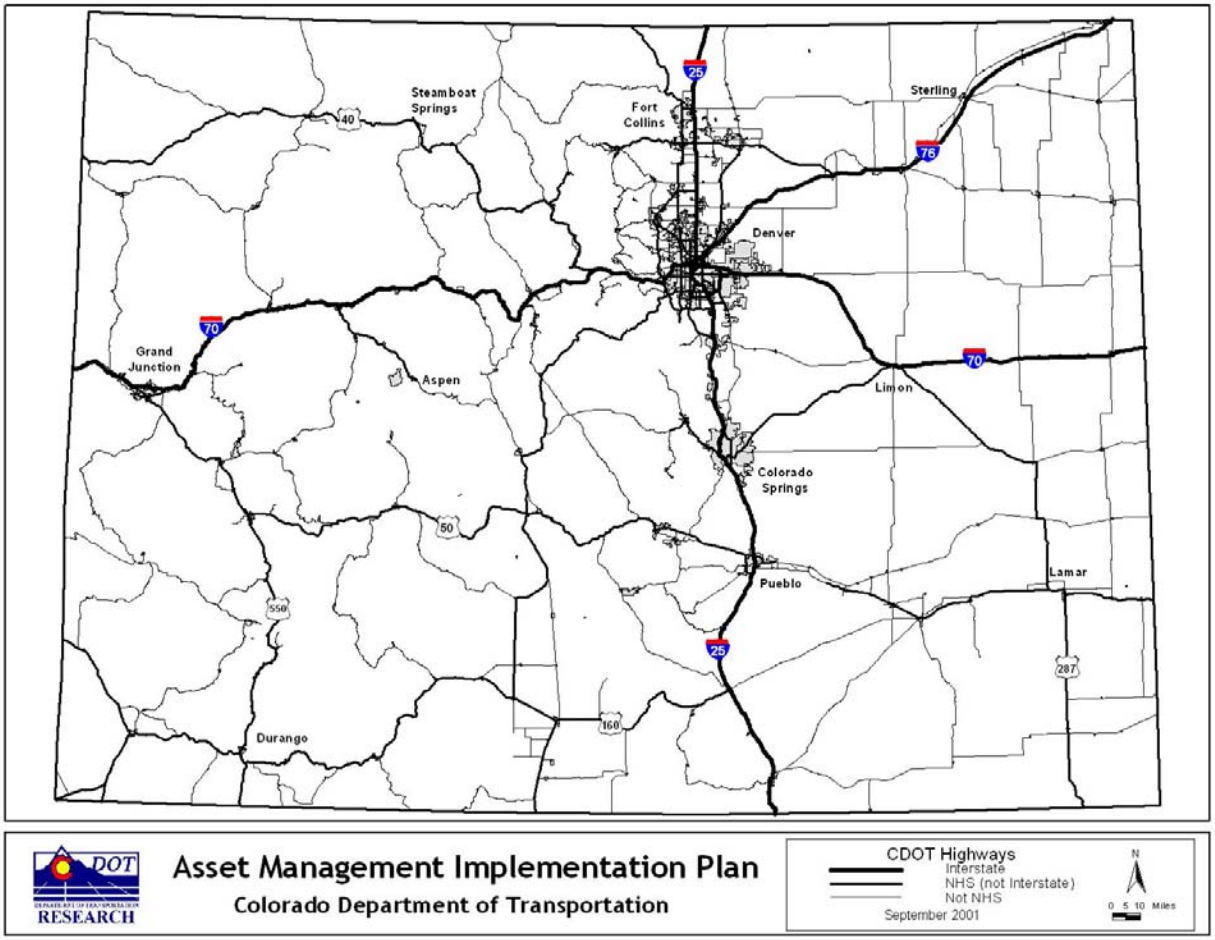

Figure 20. Colorado State Highway System

5.2 Other Examples of Tiering Used within CDOT

Five other examples of tiering utilized within the Department are illustrated below to provide additional background and understanding before presenting the recommendations. Three examples are for the highway system while the other two relate to non-highway modes – aviation and railroads. The tiering examples shown below are:

- Highway System – Maintenance Levels of Service for Snow Removal;
- Highway System – Statewide Significant Corridors (currently inactive);
- Highway System – Strategic Projects;

- Aviation System – Statewide Airport Roles and Functional Classification; and
- Railroads – Rail Corridors of State Significance for Preservation.

Other tiering structures can be found for various purposes ranging from urban functional classification and congestion management monitoring to that for the Highway Performance Monitoring System (HPMS).

Highway System Tiering – Maintenance Levels of Service for Snow Removal. As part of the Maintenance Levels of Service effort first implemented in 1998, the desired or targeted results and necessary levels of investment for Snow Removal and Traction Application were developed using a tiered structure of the highway system. Snow Removal and Traction Application accounts for some $30 million per year or nearly 20 percent of CDOT's $157 million annual Maintenance Budget. The tiering used for this application is an extension of the highway category tiering presented above for the Pavement Program. The Maintenance Levels of Service for Snow Removal extended that tiered structure by further stratification of the highway categories into traffic volume range intervals to permit a finer gradation of desired outcomes within each category. This approach also allowed a segment of highway in a lower level category to receive a higher level of results if traffic volumes warranted.

Highway System Tiering – Statewide Significant Corridors (Inactive). CDOT's Division of Transportation Development (DTD) created a tiered classification scheme named the Statewide Significant Corridors (SSC) as part of the development of the first statewide transportation plan, the 2015 Plan, in the mid 1990s. The purpose of the SSC was to create a state-perspective version of the National Highway System classification scheme shown earlier in Figure 20 to help with identification of priorities for the 2015 Statewide Transportation Plan. Criteria for development of the SSC included the following:

- Interstate Mobility Connections;
- Intrastate Connectivity;
- Efficient Movement of People and Goods;

- Intermodal Linkages; and
- Multimodal Utilization.

The highway portion of the multimodal SSC is shown on Figure 21 and was largely a high-priority subset of the NHS network although some non-NHS highways were included. While this initial effort at developing a state-perspective hierarchy to the highway system was not subsequently retained, the need for a state-perspective hierarchy to the highway system remains.

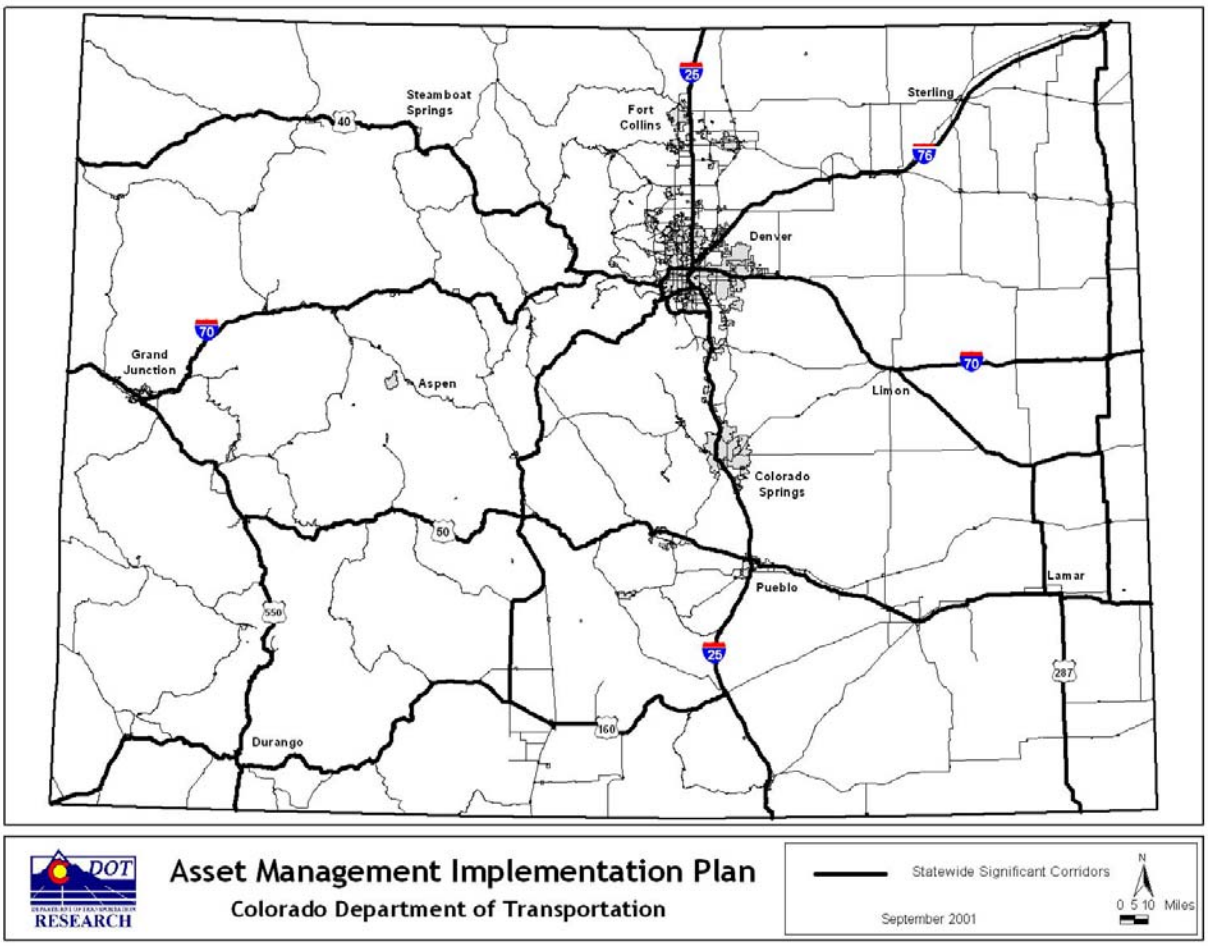

Figure 21. Statewide Significant Corridors (SSC)

Highway System Tiering – Strategic Projects. The Strategic Projects Investment Category is a program currently comprised of 28 high-cost, high-priority projects receiving accelerated funding to expedite their completion. These projects were selected using the Statewide Significant Corridors as a starting point (though not limited to the SSC) to address three major factors:

- Corridors of state and regional significance;
- The inordinate amount of time required to complete major projects; and
- To provide for a more aggressive response to the demands for mobility.

While the development of the Strategic Projects Investment Category was not done with the specific idea of creating a tiering structure, its effect has been to create a hierarchical perspective on the state highway system that cuts across the roadway category tiering structure described above. Figure 22 shows a map of the 28 Strategic Projects.

Aviation System Tiering – Division of Aeronautics' Statewide Airport Tiering Scheme. CDOT's Division of Aeronautics (DOA) is charged with assisting the state's public-use airports in improving the state air transportation system. While the state's aviation system is anchored by Denver International Airport (DIA), the most modern commercial airport in the nation and one of the busiest airports in the world, the state Division of Aeronautics focuses its efforts on the other 78 public-use airports in the state. The Federal Aviation Administration (FAA) has its own classification and tiering of state's airport system from a national perspective similar to FHWA's National Highway System (NHS) perspective for roadways. The DOA has implemented its own state-perspective tiering scheme to assist it in goal setting and funding decisions with its $11 million annual budget. The state DOA's tiering scheme has three levels of importance – Major, Intermediate, and Minor. Assignment of an airport to one of these tiers is based on five factors: aviation activity level, expandability, economic impact, service area coverage and emergency service role, and history of investment.

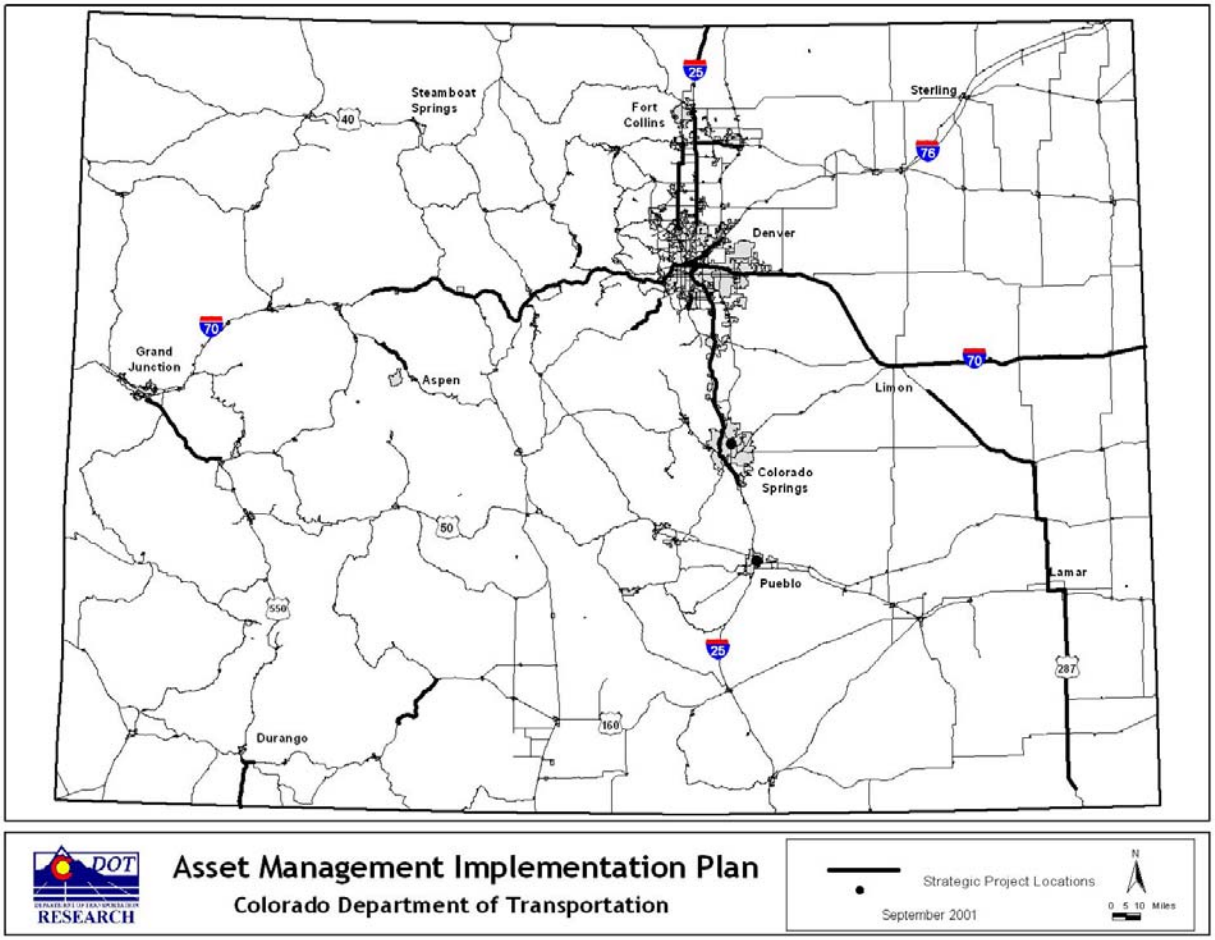

Figure 22. Strategic Projects

Based on these criteria and a weighting method for their consideration, the DOA has assigned the state's 78 public-use airports (not including DIA) to the tiers as shown in Figure 23. The tiering scheme developed by the DOA is being directly incorporated into the Asset Management Plan without modification.

Railroad Tiering – Rail Corridors of State Significance for Preservation.

Colorado has approximately 3,000 miles of railroad track within its borders, with about 90% of it owned and operated by two national railroad companies - the Union Pacific (UP) and the Burlington Northern Santa Fe (BNSF). CDOT's primary interest in railroads is in

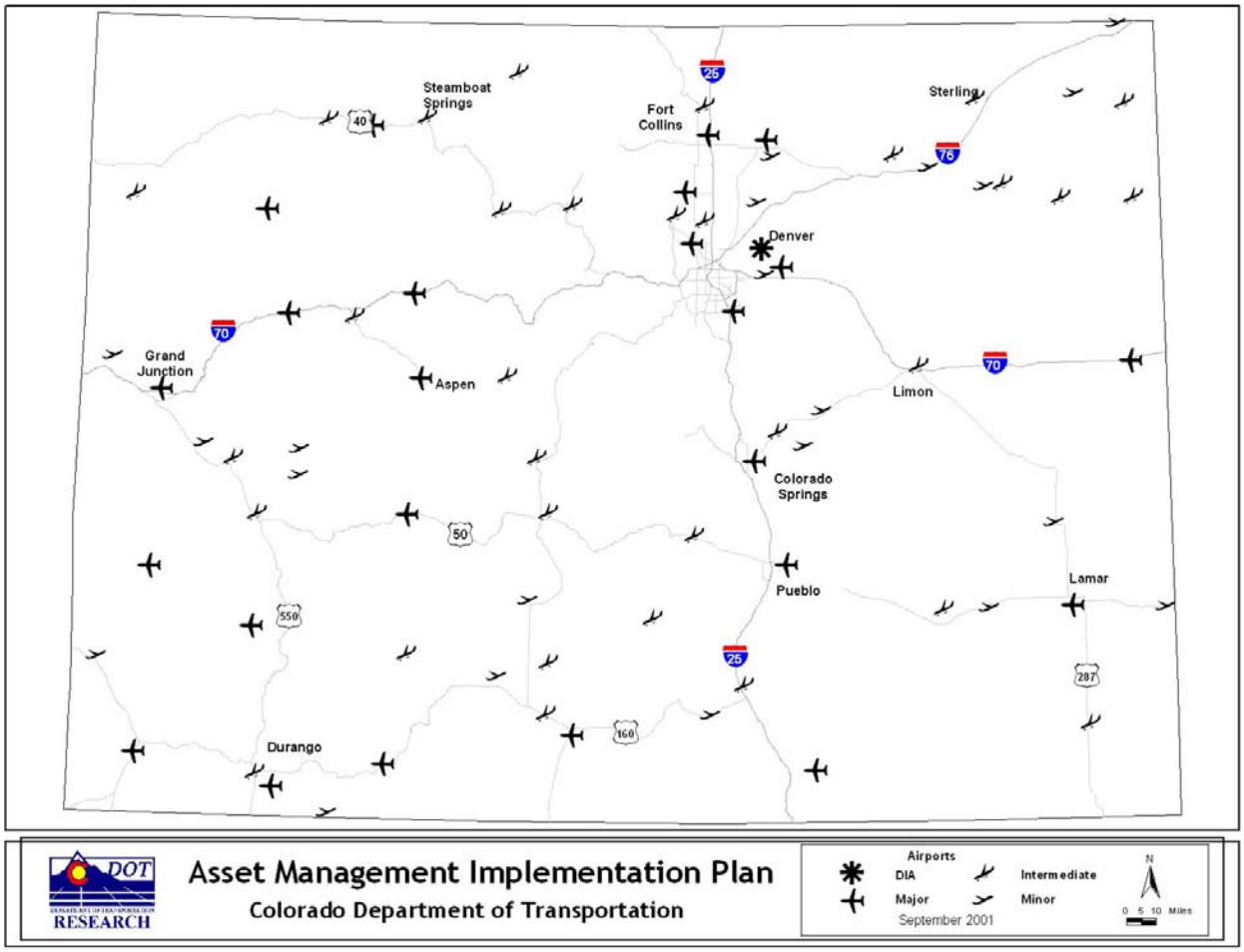

Figure 23. Colorado Airports by Functional Level

ensuring that existing rail rights-of-way that are of significant state interest are preserved for possible future transportation use. CDOT is also interested in preserving the option for possible future rail use within existing and planned highway rights of way. Freight and passenger rail service could improve the mobility within the state as well as reduce the demand and impacts to CDOT's highway system.

To support these interests, CDOT identified Rail Corridors of State Significance, as shown in Figure 24. The significant rail corridors primarily connect the urbanized communities along the Front Range or connect the Denver metro area to points east and west. The highest priorities among these significant rail corridors are those at risk of abandonment

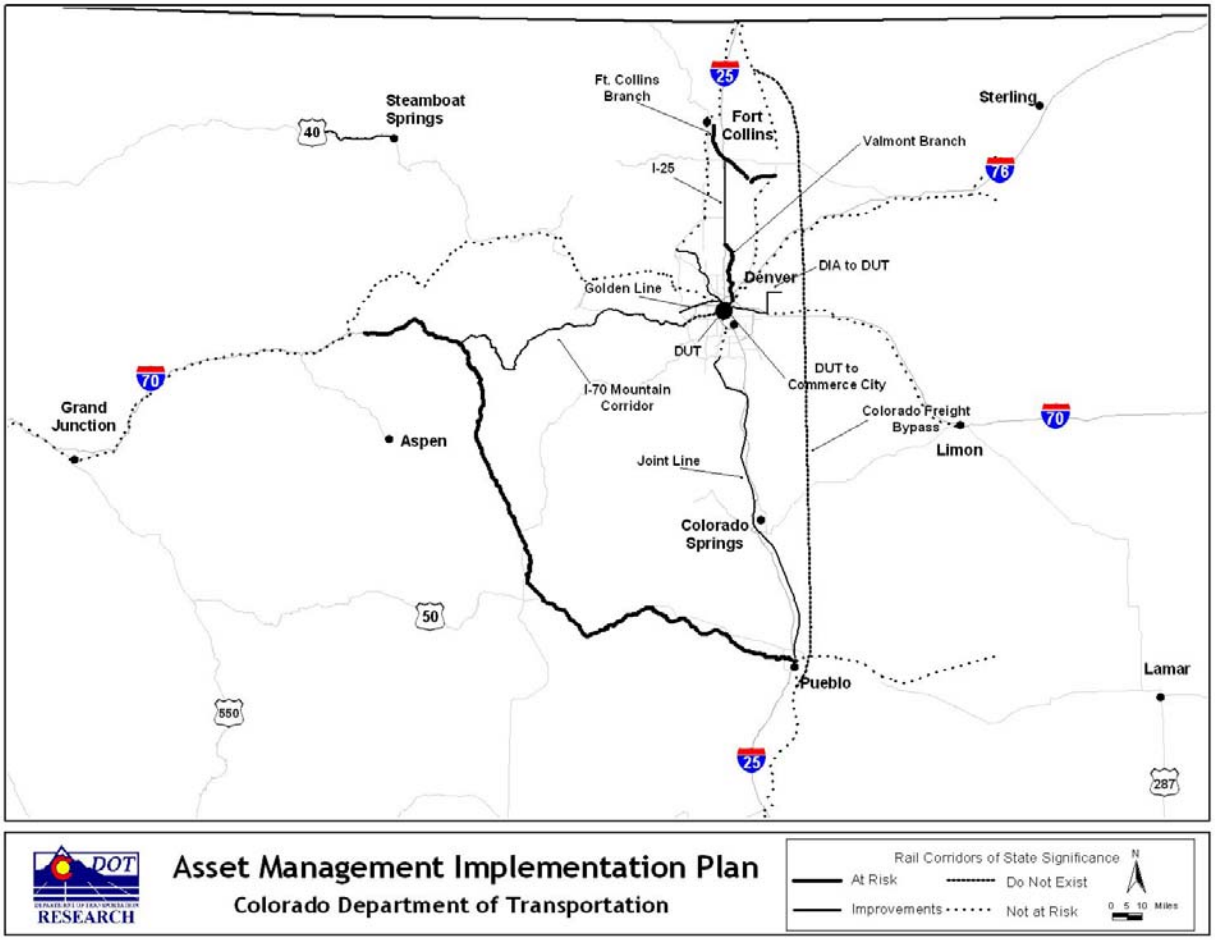

Figure 24. Significant Rail Corridors

where action by CDOT and others might be necessary to keep the right-of-way available for transportation uses. When the North Avondale to Towner railroad line in southeast Colorado was proposed for abandonment, CDOT purchased the line and initiated the process for its lease and eventual sale to a short line railroad to maintain service to existing customers. Three other existing rail lines (all owned by the Union Pacific) are high priority corridors subject to abandonment – the Tennessee Pass Line over the Continental Divide from Pueblo (currently unused), the Valmont Branch in the northern part of metro Denver, and the Fort Collins Branch connecting Fort Collins and Greeley. Both the Valmont Branch and the Fort Collins Branch have been identified in major corridor planning studies as opportunities for future passenger rail services. This tiering of the state's railroads and

highways for existing or future rail use is incorporated into this Asset Management Plan without modification.

Other Modal Classifications – Transit and Bicycles. In addition to the tiering applications noted above, transit and bicycles deserve special mention. CDOT's Intermodal Program passes through Federal transit funds to various smaller communities that do not receive direct awards from the Federal Transit Administration (FTA). CDOT has classified but not tiered the transit systems in its Intermodal Program into five categories – specialized, rural, resort, urban, and intercity. Regarding bicycle facilities, CDOT staff has identified a candidate list of High Priority Bicycle Corridors, but these have not been acted upon by the Transportation Commission.

5.3 Development of Additional Tiering Perspectives for the Roadway System

The critical lesson from the review of the existing tiered classification structures presented above is that each tiered structure addresses a set of objectives or helps in answering a set of questions. The answer to the question of "what should the tiered structure for the highway system be" can best be answered if it is clear what role and purpose the tiering has in the decision-making process, and what unmet need it serves. Section 5.3 is divided into four subsections as follows.

- Need for a modified tiered structure;
- Results of the outreach effort;
- Results of research into tiering used by other states; and
- Recommendations.

Need for a Modified Tiered Structure for the Roadway System. The general goal of a modified tiered structure for the roadway system is to improve the investment decision-making process. The fact that development of additional tiering was made a part of this Asset Management Research Project suggests that the existing tiering structure based on the

major roadway categories from the National Highway System was not deemed adequate for some investment decision-making or performance targeting or monitoring. The fact that the Statewide Significant Corridors tiering scheme was developed several years ago further supports that conclusion. The fact that the CDOT Division of Aeronautics developed its own statewide perspective on airport tiering to complement the national FAA classification scheme also supports this idea. Thus, it appears that the NHS-based tiering structure alone is not deemed adequate for asset management purposes. The NHS-based tiering structure alone does not appear to provide adequate discrimination and alignment of the roadway system assets to understand customer expectations, support setting objectives, forecasting results and financial requirements, making investment decisions, and monitoring and reporting actual results. The Maintenance Levels of Service for Snow Removal addressed this issue by introducing traffic volume range intervals to its tiering structure.

Results of the Outreach Workshop on Tiering. A half-day outreach workshop on tiering was conducted in October 2000 as part of this Asset Management Research Project. Its purpose was to identify the factors deemed most important to the participants in tiering of the transportation system. Eleven Transportation Planning Regions (TPR), Metropolitan Planning Organizations (MPOs), or transit agencies participated in the workshop, representing a cross-section of rural and urban interests. The essence of the results was that three categories of factors were deemed most important to the workshop participants in terms of tiering of the transportation system:

1. **Functional role** of the asset (commuter, recreation, inter- versus intraregional, freight, etc.).

2. **Utilization characteristics** of the asset (volume, congestion, etc.).

3. **Transit, intermodal, or alternate mode aspect** of the asset.

Research on Tiering by Other States Departments of Transportation. A review of the tiering or classification schemes used by 13 other state DOTs for planning and investment decision-making found two themes relevant to this research. One was a use of

the NHS-based scheme similar to that used by CDOT. The other was a breakout of the state roadway system into two major categories – interregional and intraregional – with an emphasis on the interregional system. The rationale for this second classification scheme – inter- versus intraregional – is that the state DOT is usually the sole provider of significant interregional surface highway transportation, while it is a partner in the intraregional surface transportation system. Thus the investment decision-making, goal setting, monitoring, etc., of these two categories of assets could be significantly different even for the same NHS roadway category. Customer expectations, goal setting, investments, and monitoring within an intraregional setting could be viewed as part of the intraregional system and in consultation with the intraregional agency partners, not just the state highway system alone. Interregional goal setting, investments, and monitoring fall nearly exclusively on the state DOT.

The California Department of Transportation (Caltrans) developed its original Interregional Road System (IRRS) Strategic Plan in 1990, with an update in 1998. The underlying premise of the IRRS Strategic Plan is that Caltrans' role in intraregional transportation is as a significant partner, and its results and investments must be in consultation with its other partners, while in interregional surface roadway transportation it is the sole significant provider.

The Minnesota Department of Transportation (MnDOT) recently completed its first Interregional Corridor Study that identified two levels of interregional corridors. Specific recommendations from that study with direct relevance to CDOT Asset Management include the following:

- MnDOT should adopt the Interregional Corridor System into its State Transportation Plan;
- MnDOT should establish operating guidelines for interregional corridors; and
- MnDOT should establish indicators for monitoring performance of the interregional corridor system.

Recommendations for Additional Tiering of the CDOT Highway System. Based on the outreach session, discussions with CDOT staff, and research into the highway system tiering of other states, the following five principal factors have been identified as important to the development of additional tiering:

- NHS-based highway categories as currently used;
- Connectivity role: inter- versus intraregional;
- Traffic volumes/level of utilization;
- Freight role or level of trucking; and
- Transit role.

The general recommendation for a modified tiering structure that considers these five factors is given below and uses an inter- vs. intraregional designation as its top-level tiering factor.

- Tier 1 – Inter- vs. intraregional classification of the highway system, with CDOT's primary interest being in the interregional facilities.
- Tier 2 – Primary vs. secondary for interregional highways; other second-level tiering as appropriate within regions for intraregional highways.

Determination of Tier 1 would be primarily related to the significance of the highway's function of connecting regions vs. providing travel within regions. Information required to make this determination would include a definition of regions/communities to be connected and travel data supporting the inter vs. intra role. Determination of Tier 2 could be based on factors such as the NHS designation, traffic volumes, freight role or trucking level, and transit designation and might be different for inter vs. intraregional roadways. At least a two-level Tier 2 is suggested for the interregional highways. Second-level tiering of the intraregional roadways would be done in consultation with the intraregional transportation partners within the urbanized or other designated areas. It could be based on hierarchical classifications schemes already in place for a region that account for the role that CDOT facilities have in a blended regional highway network. Special consideration should be

given to the intraregional segment of major interregional roadways such as I-25 through metro Denver. Caltrans specifically highlights the dual role of such segments in its Interregional Road System Strategic Plan. Important off-system highways should be considered for inclusion in the CDOT tiering scheme and designated as being of "significant state interest." These are more likely to be located within the intraregional highway systems as opposed to the interregional highway systems and would include highways such as E-470 in metro Denver.

Figure 25 shows a sample assignment of CDOT's roadway system to the interregional category without regard to the primary or secondary level within the interregional category.

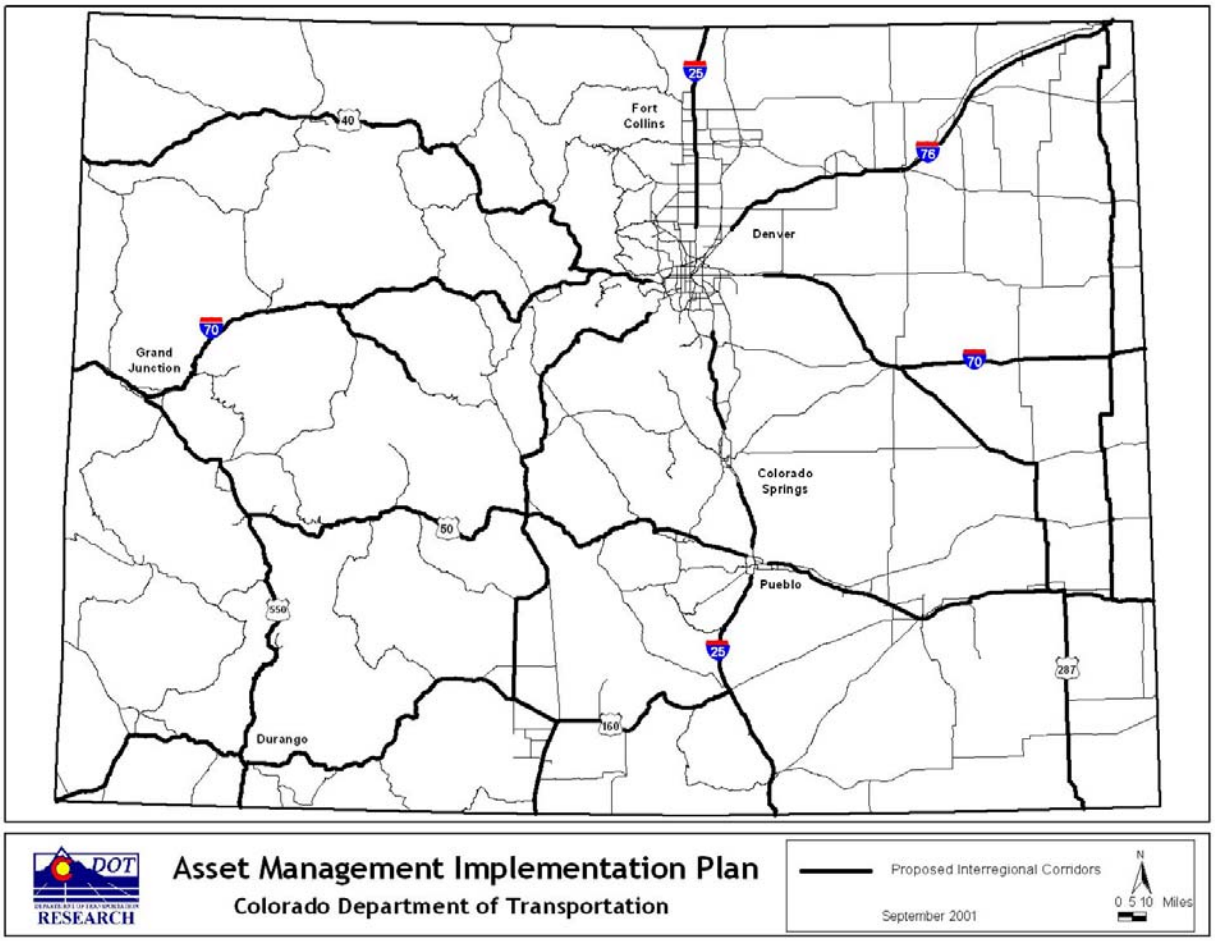

Figure 25. Proposed Interregional Corridors

A roadway is generally determined to be interregional in nature if a high percentage (threshold yet to be determined) of its traffic is traveling between regions, not within regions, and if there is not a higher level roadway that can be used in its place for interregional travel. Some CDOT highways that were originally interregional are now intraregional because of construction of newer higher level facilities (e.g., the Interstates) that serve the interregional trips and because of the fact that some one-time separate regions have grown together such as Boulder and Denver. This sample tiering has results slightly different than the Statewide Significant Corridors but may be more defensible because it recognizes those situations where CDOT is the sole provider of surface transportation as opposed to being a significant partner among many providers. In summary, this inter- versus intraregional approach would help CDOT set targets for results in a fashion that recognizes that customer needs and expectations and thus types and levels of investment are likely to be very different in these two categories of facilities.