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Final Report

LIFE CYCLE COSTING

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COLORADO DEPARTMENT OF TRANSPORTATION
RESEARCH BRANCH

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16. Abstract

The research project was initiated by the Colorado Department of Transportation (CDOT) to develop guidelines for determining the long-term costs of adding additional capacity and other related transportation improvements to the state highway and bridge system. Future costs, including ongoing maintenance, rehabilitation, and replacement costs have not been traditionally considered when a project is advanced. At the planning level this project allows for CDOT to estimate the future cost of adding capacity to the transportation system and to assess the impacts that transportation related projects will have on future year budgets

In completing the project a methodology was proposed that would capture the incremental increase in long-term project costs associated with adding additional capacity to the system. Incremental costs were defined as not only geometric increases, but also include such things as roadway and bridge maintenance, ITS deployment and maintenance, and roadway and bridge rehabilitation. Incremental costs were identified as long-term projects costs that CDOT would have to account for in future budgets.

As anticipated, research results reflect that long-term project costs associated with capacity improvements to the state transportation system will require additional financial resources in future years.

Implementation:

The proposed guidelines for performing life cycle costing for CDOT will allow for the development of estimates of future expected revenues necessary to maintain and rehabilitate the state's transportation system on a project basis.

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TABLE OF CONTENTS

TABLES

1. Executive Summary

The research project was initiated by the Colorado Department of Transportation (CDOT) to develop guidelines for determining the long-term costs of adding additional capacity and other related transportation improvements to the state highway and bridge system. Future costs, including on-going maintenance, rehabilitation and replacement costs have not been traditionally considered when a project is advanced. At the planning level this project allows for CDOT to estimate the future cost of adding capacity to the transportation system and to assess the impacts that transportation related projects will have on future year budgets

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The proposed guidelines for performing life cycle costing for CDOT will allow for the development of estimates of future expected revenues necessary to maintain and rehabilitate the state's transportation system on a project basis.

2. Background

The job of expanding and maintaining 9,200 miles of state highways, 1,950 bridges and an expanding ITS system has become increasingly more difficult for CDOT. The state's rapidly growing population and even faster growing Vehicle Miles of Traveled coupled with recent reduced budgets has made it difficult for CDOT to carry out its mandated activities today and in future years. The 2030 State Transportation Plan suggests that travel is expected to grow significantly over the next 26 years and that currently projected revenues will fall dramatically short of what it would take to build and maintain the transportation system to desired levels. Specifically, issues relating to Senate Bill 1, the Taxpayers Bill of Rights, Amendment 23 and the economic downturn after 9/11 have directly and indirectly negatively affected CDOT's revenue stream.

At the federal level, the long delay in passing a transportation reauthorization bill provided further fiscal uncertainty. The net effect of financial issues at the state and federal level has resulted in a significant drop in revenue for highway related activities. In 2001, revenues from all sources for CDOT related activities were approximately $1.4 billion. In contrast, the most recent budget (2006) provides only $817 million despite the fact that demand and expectations from users of the system has and will continue to grow. It has become clear that existing allocation processes are not adequate in this era of diminishing resources and ever increasing demand.
To address financial related issues, CDOT developed a Resource Allocation process by which revenues estimates are allocated to five CDOT Investment Categories. The Performance Measures Program enables CDOT to track system performance. The five Investment Categories are:

1. **Safety-Programs -** Services and projects that reduce fatalities, injuries, and property damage for all users of the system.
2. **Systems Quality -** Activities, programs and projects that maintain the function and aesthetics of the existing transportation system.

3. **Mobility-Programs** - Services and projects that provide for the movement of people, goods and information.
4. **Program Delivery** - Support functions that enable the delivery of CDOT's programs and services.
5. **Strategic Projects**-The 28 high priority projects that have been committed for accelerated funding.

Within these five Investment Categories, each of CDOT's program areas reside. For example, the Maintenance program is distributed among the Safety, Systems Quality, Mobility and Program Delivery Investment Categories, whereas the ITS program areas reside within the System Quality and Mobility Investment Categories.

3. Purpose

The purpose of this research project is to develop guidelines that allow CDOT to capture the long-term costs of adding additional capacity and other transportation related improvements to the state highway and bridge system. Historically, only the initial cost of a project has been analyzed to determine whether a project would be implemented. Future costs including maintenance, rehabilitation and reconstruction/replacement costs have not been traditionally considered in the decision making process to determine if a project moves forward. However, these costs are significant and have an impact on future budgets.

Once these additional recurring costs have been identified, they can be allocated to the appropriate CDOT investment categories (Mobility, System Quality, Program Delivery and Safety), for Transportation Commission consideration in the decision making process. It is anticipated that the results of this study will provide information that will be useful in developing future state transportation plans, the annual budget and the State Transportation Improvement Program (STIP) by alerting policy makers to the long-term impacts of current decisions.

4. Methodology

In developing long-term costs associated with increasing the assets of the state transportation system, recurring costs for maintenance, rehabilitation and reconstruction/replacement will be developed for each proposed asset. The process will also account for any incremental increases to the system and the associated recurring costs. For purposes of this project, incremental increases to the transportation infrastructure are not only geometric increases (i.e. capacity), they also include activities such as ITS deployment, Noise Walls, and Guardrail, etc. The proposed analysis period will be 40 years based on pavement life, but various "snapshots" reflecting the 6-year STIP and 2030 Statewide Transportation Plan can also be accommodated. Output will be reflected in a template that will provide *Year of Expenditure Dollars* and *Constant 2005 Dollars*.

Steps involved in developing the incremental costs are as follows:

1. **Develop a typical section for the existing facility -** This should include components such as pavement width including travel lanes, passing lanes, shoulder width as well as right-of way for both highway and bridge facilities. Existing components such as lighting, guardrails, noise walls, barriers and ITS should also be noted.

2. **Develop a typical section that includes the proposed improvement(s) -** This should include pavement width with additional travel lanes, passing lanes and shoulder-related improvements as well as additional right-of-way for both highway and bridge facilities necessary to implement the proposed facility. In addition, components such as the addition of lighting, guardrail, noise walls, barriers, ITS improvements or other transportation related improvements having recurring maintenance, rehabilitation and reconstruction/replacement costs should be identified.

3. **Determine the incremental increase over the existing facility -** This analysis should define and include all incremental improvements to the existing highway or bridge structure that should be tracked over the life of the project. Incremental costs are improvements above and beyond those on the existing facility. Specifically, the analysis

should identify the additional pavement width, additional travel lanes, passing lanes, and shoulder width expansions and other components such as lighting, guardrail, noise walls, barriers, ITS improvements or other transportation related improvements having recurring maintenance, rehabilitation and reconstruction/replacement costs.

The following four categories and the activities associated with them will provide the basis for developing initial and recurring project costs for highway and bridge projects.

Initial Construction

- Construction
- Preliminary Engineering
- Construction Engineering
- Traffic Control
- Right-of Way
- ITS
- Guard Rails
- Barriers
- Lighting
- Noise Walls

Maintenance

- Planning and Training
- Road Surface
- Roadside Facilities
- Roadside Appearance

- Traffic
- Structures
- Snow and Ice Control
- Equipment/Buildings/Grounds
- Tunnels

Rehabilitation

- Rehabilitate
- Preliminary Engineering
- Construction Engineering
- Traffic Control
- Replace/Update ITS
- Guard Rails
- Barriers
- Lighting
- Noise Walls

Reconstruction/Replacement

- Reconstruct
- Preliminary Engineering
- Construction Engineering
- Traffic Control
- ITS
- Guard Rails

- Barriers
- Lighting
- Noise Walls

Roadway

There is a significant data set relating to roadway construction and preservation activities. Some general assumptions developed by CDOT and incorporated into the 2005 Pavement Design Manual should be used to guide and frame the project cost analysis.

- The analysis period for asphalt pavements is 40 years. The initial design period is 20 years and the rehabilitation schedule suggests a 2" Hot Mix Asphalt (HMA) overlay at 10, 20, and 30 years.
- The analysis period for Portland Cement Concrete Pavements (PCCP) is 40 years. The initial design period is 30 years and the rehabilitation for PCCP is either:

    1. PCCP with dowel and tie bars will require 50% full width diamond grinding of ¼" to restore reliability at 22 years with joint resealing and ½% slab replacement in the travel lanes.
    2. PCCP without dowels or tie bars will still require full width diamond grinding of ¼" with joint resealing and 1% slab replacement in travel lanes.

Or

- Another rehabilitation strategy for PCCP is to provide a 2" HMA overlay at 20 and 30 years or a 3" HMA overlay at 20 and 30 years in a high volume urban area.

Bridge

CDOT does not currently perform life cycle cost analysis on proposed bridge improvements or replacements. However it does have data on what it currently costs to perform bridge rehabilitation related activities. It is anticipated that over the next 2 years that CDOT will

employ the preservation module of PONTIS, the CDOT bridge management system, to determine a life cycle cost analysis.

Output from the PONTIS preservation module will recommend specific work types and frequency of application as well as the cost to maintain a bridge structure at a certain "Health Index" for each work type. Specific activities should include maintenance and bridge deck replacement. Until the PONTIS preservation module is fully operational, it is suggested that for each bridge capacity improvement project that staff confer with staff from the Bridge Section to establish an estimate of cost and frequency for rehabilitation and replacement activities. However, it is important to note that much of the ongoing bridge maintenance is captured in the structures Maintenance Program Area component of the CDOT Maintenance budget and that this information is bridge specific.

ITS

The ITS program and its application is anticipated to grow and become a more significant component of projects that add capacity to the state highway system. Several recent studies performed by CDOT including the *ITS Management System Framework, the ITS Management System Requirement Report and the ITS Maintenance Management Framework* attest to the growing importance of ITS within CDOT, the latter of which addresses life cycle costs.

While certain data on ITS applications is available, it has not been consistently collected for all applications. The ITS Branch is currently developing a reporting system that will allow for CDOT to perform life cycle cost analysis based on actual maintenance and replacement costs. CDOT has identified over 30 ITS applications ranging from Automatic Traffic Recorders to various levels of Variable Message Systems (VMS). Over 100 specific activities relating to maintaining and replacing these applications have been identified. To simplify the process, the 100 plus activities have been subsumed under four major categories for each ITS application in an attempt to develop a life cycle cost for each ITS application. The categories are preventative, routine, corrective and replacement. *Preventative activities* are scheduled maintenance activities.

Routine activities are non-scheduled maintenance activities. *Corrective activities* are those involving fixing a problem with a device or component. *Replacement activities* are those involving replacement of a device or component. Until the database is sufficiently populated, it is suggested that staff confer with CDOT ITS staff to establish an estimate of cost and frequency for maintenance, rehabilitation and replacement activities.

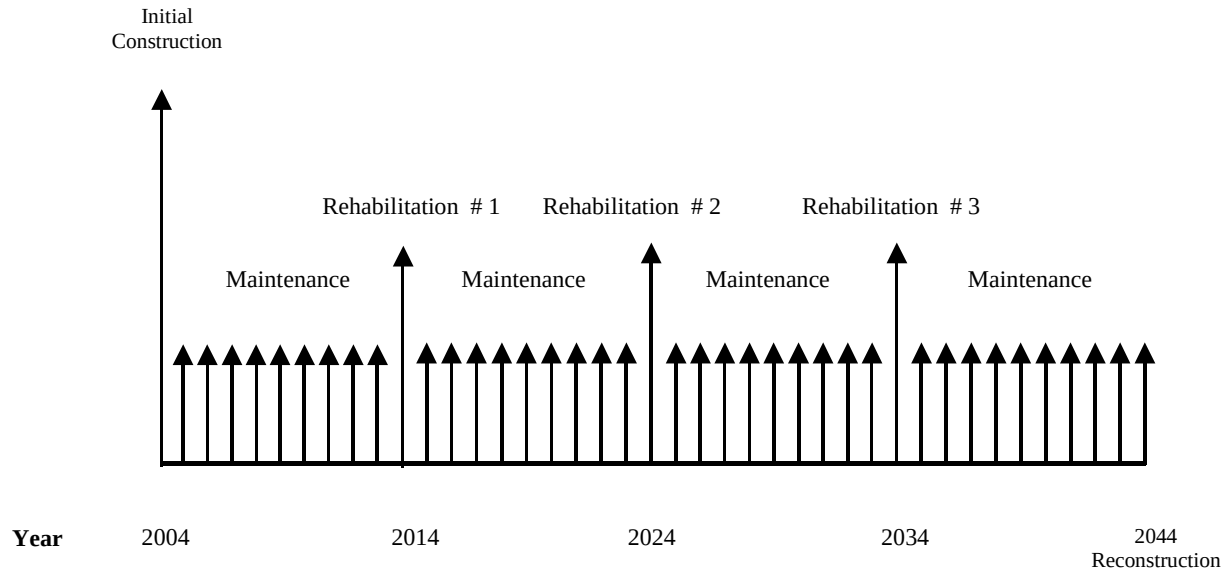
Variable costs and how future year expenditures are expressed are key concerns in refining project costs and allocating them back to the current and future year STIPs and state transportation plans. Following is some brief guidance relating to each.

Variable Cost - Since construction, maintenance, rehabilitation and reconstruction/replacement costs vary throughout the state based on topography, climatic and other conditions, it is proposed that where available the data used to develop the initial and recurring project costs for all transportation improvements should be retrievable at the CDOT region, county or route and reference point specific location.

Future Year and Constant Dollar Costs -Future costs or *Year of Expenditure Dollars* should be developed by multiplying the average annual increase for that activity against the most recent expenditure for that activity, taking into consideration what year that activity would occur. For example, if a major rehabilitation project were estimated to cost $2,500,000 in 2005 the cost to perform that activity in 2015 based on the Pavement Management Guidelines would be $3,500,000 based on a 5% average annual increase for that activity. To be compatible with costs developed for the 2030 Statewide Transportation Plan, project related costs should be expressed as *2005 Constant Dollars*. For instance, if a resurfacing project (rehabilitation) were said to cost $3,500,000 in *Year of Expenditure Dollars* in 2015, it would be discounted back to *2005 Constant Dollars* by discounting the 2015 project cost by 5% per year.

5. Guidelines for Determining Recurring Costs

It is suggested that, in addition to developing project cost for the four major activities, (Initial Construction, Maintenance, Rehabilitation and Reconstruction/Replacement) that a diagram be developed that graphically shows the recurring activities associated with a project's life. The following diagram reflects the significant activities of a major capital project over a 40-year period. Ideally, this figure can be developed for highway, bridges and for ITS applications.



Initial Construction

Although the bulk of a project's cost are directly associated with pavement and related sub-grade activities, other activities are not always fully accounted for in project development. While the majority of initial construction activities (i.e., construction, preliminary engineering, construction engineering and traffic control) are developed by the project engineer for highway and bridge projects, other potential items including ITS, guardrails, noise barriers, barriers and lighting, signalization and their associated costs, are often not accounted for in project development. Expenditure data for each category can be disaggregated to the CDOT region level, county or by route and reference point. These are important financial considerations because, at some time in

a project's life, some, if not all, of these must be maintained, rehabilitated or reconstructed/replaced. The cost to maintain, rehabilitate, and reconstruct/replace these additional items will be accounted for under the maintenance, rehabilitation and reconstruction/replacement categories listed below. Activities under Initial Construction are associated with all Investment Categories.

Maintenance

CDOT is expected to spend approximately $210.0 million on maintenance activities in 2006. Unlike construction and rehabilitation costs, which occur only periodically, maintenance costs recur annually. In an effort to track maintenance related expenditures and performance, CDOT developed its Performance Budgeting System for Maintenance. This system annually measures the conditions of over fifty activities or system items on the state's highway and bridge network. Examples of these specific activities include patching by hand or machine, sealing of pavement cracks and joints, seal coating, balding unpaved surfaces and shoulders, cleaning drainage structures, cleaning and shaping ditches, repairing slopes, maintaining stream beds, sweeping the road surface, picking up litter and trash, controlling vegetation, maintaining roadway signs and lighting, painting bridges, snow plowing and ice control, removing snow and sand. These activities or system items are reflected in the nine Maintenance Program Areas (MPAs) below. They are:

- Planning and Training
- Road Surface
- Roadside Facilities
- Roadside Appearance
- Traffic
- Structures
- Snow and Ice Control
- Equipment/Buildings/Grounds

- Tunnels

Expenditure data for each MPA is available from 1999 to the present. Expenditure data for each category can be disaggregated to the CDOT region level, county or by route and reference point. To gain a better understanding of the annual maintenance expenditure stream it is recommended that information be collected for each of the nine MPAs.

In calculating the future maintenance expenditures it is suggested that the average annual percentage increase for each category in the 1999-2004 expenditure data be applied to reflect year of expenditure dollars. For example, if it were determined that the snow and ice control MPA grew at an annual rate of 3.0% for the six year period 1999-2005 that percentage would be used to develop future year expenditures. If the base year of the project is 2006 and the 2005 expenditure was $1,500 per lane mile, the 2006 snow and ice control expenditure would be $1,545 per lane mile in year of expenditure dollars or $1,500 in 2005 dollars. A similar level of analysis should be performed for the remaining eight MPAs. The bulk of roadway maintenance related activities are associated with the Safety, System Quality, Mobility and Program Delivery Investment Categories.

Bridge maintenance is reported in the Structures MPA in the maintenance budget and is associated with the System Quality Investment Category. Information for each bridge is reported by structure number and by specific geographic location.

ITS maintenance is not currently accounted for in any of the nine MPAs of the CDOT maintenance budget, but rather is a program area under the System Quality Investment Category. As mentioned on page 7, the ITS maintenance reporting system is currently being developed. It will collect information for each ITS project application based on four types of maintenance categories (Routine, Preventative, Corrective and Replacement) and 100 plus specific activities subsumed under the four categories for each ITS application. Once initiated and when sufficient information is collected, the reporting system will provide cost and frequency of application

information for each of the 30 or more applications. It is suggested that the expenditure data be expressed by CDOT region, county, or by route and reference point for each ITS application.

Rehabilitation

Specific rehabilitation activities, associated costs and their timing relative to roadway pavement improvements and bridge deck replacements include Preliminary Engineering, Construction Engineering and traffic control, are developed based on the 2005 Pavement Design Manual. These costs are presented in Year of Construction Dollars or what it would cost today to rehabilitate a roadway 10, 20, and 30 years from now, not what it would cost in those future years if construction inflation were taken into consideration.

In developing rehabilitation costs, current CDOT practice suggests that the Cost Data Manual be used unless up-to-date bid prices are available for similar work in the generalized area. CDOT has developed a normalized unit cost at the state and CDOT region level for HMA and PCCP based on projects constructed from 2000 through 2003.

In calculating the future rehabilitation expenditures, it is initially suggested that the average annual percentage increase from 2000 through 2003 expenditure data be applied to reflect *Year of Expenditure Dollars* for future rehabilitation projects. For example, if it were determined that a rehabilitation project (Pavement, PE, CE TC) would require $2.5 million in 2004 and the average annual rate of increase in HMA or PCCP projects was 5.0%, the Year of Expenditure Dollars necessary to complete the project in 2014 would be approxiamety $3.75 million. These rehabilitation activities are associated with the System Quality Investment Category.

Reconstruction/Replacement

This component of the project cost analysis takes into consideration the reconstruction of the entire pavement including the types of activities listed above under initial construction including the reconstruction or replacement of a bridge. While the majority of initial construction activities (i.e. construction/reconstruction, preliminary engineering, construction engineering and traffic control) are developed by the project engineer, a host of other potential items including ITS, guardrails, noise walls, barriers, lighting and signalization have to be accounted for as future year project expenditures. For roadway surfaces this may occur in 40 years, for bridges as far out as 75-100 years. However, many of the other activities related to full long-term project costing have relatively short life cycles and must be replaced relatively often over a project's life. For example, an overhead variable message sign may only have a life cycle between 10 and 20 years, requiring its replacement at least once, if not twice over the life of the roadway. It is important that these additional costs are fully reflected as expenditures in future years. Typically, Reconstruction/Replacement cost are associated with the System Quality Investment Category.

6. Future Project Cost Estimation

Estimates for future costs can be made using *Constant* or *Year of Expenditure Dollars*. *Constant Dollars* reflect dollars with the same or constant purchasing power over time. The cost of performing an activity would not change as a function of the future year in which it would be accomplished. For example, if Hot Mix Asphalt (HMA) cost $20 per ton today, then $20 per ton should be used for future year HMA cost estimates. Alternatively, *Year of Expenditure Dollars* represents dollars that fluctuate in purchasing power as a function of time. They are normally used to reflect future price increases due to anticipated inflation. *Year of Expenditure Dollars* reflect the future year in which the activity is performed. For example, if HMA costs $20 per ton today and the cost of doing business is expected to rise by 5% per year the price would rise to $21 per ton one year from now.

The estimation of project costs will be performed in two ways. The first will be compatible with the 2030 State Transportation Plan that is based on 2005 *Constant Dollars*. The second way of expressing future year expenditures will be *Year of Expenditure Dollars*; which is more compatible with budget and STIP related concerns.

For both *Constant* and *Year of Expenditure Dollars*, expenditures will be assigned to the appropriate Program Areas for each Investment Category. For example, maintenance expenditures will be reflected in the Safety, Systems Quality, Mobility and Program Delivery Investment Categories and ITS investments or maintenance in Mobility and System Quality.

The future year project costs will reflect the anticipated project costs for the proposed facility including the incremental project increase. For example, from a pavement or bridge perspective, if the roadway surface goes from 28 feet (two 12-foot lanes and two 2-foot shoulders) to a 48-foot roadway surface (two 12-foot lanes including One 12-foot passing lane and two 6-foot shoulders) it is suggested that 58% of the maintenance, rehabilitation and reconstruction costs be

allocated to the existing facility and the remaining 42% reflect costs associated with the incremental increase of the project.

7. Representing Long-Term Project Costs

The following two tables reflect long-term project costs in *Constant* 2005 dollars and *Year of Expenditure Dollars* and will address the needs of meeting the requirements of the Statewide Plan as well as immediate financially relevant issues relating to budget and STIP development. They represent a *hypothetical* project and are used only to show how long-term project costs can be expressed in an easy to understand format. Attachment A **"CDOT Life Cycle Cost Analysis Guidebook"** is the Excel spreadsheet used to develop total and incremental project costs.

Each table represents an aggregation of estimated expenditures for each category, including Initial Construction, Maintenance, Rehabilitation, and Reconstruction/Replacement as a simple way of expressing long-term project costs. For example, *construction* expenditures should reflect all related activities associated with the mobility enhancing project including not only the cost to construct a bridge or roadway but other investments above and beyond that which were already in place. This might include ITS improvements, Noise Walls, Guardrail, Barriers, lighting and signalization, etc. *Maintenance* related costs should include not only pavement or bridge related maintenance costs but also those maintenance costs associated with implementing ITS and other types of maintenance activities. *Rehabilitation* cost should also include not only pavement or bridge deck related activities but also ITS and other transportation related rehabilitation activities. *Reconstruction/Replacement* activities need to reflect not only pavement construction or bridge replacement but also the costs associated with replacing noise walls, guardrails, ITS devices, and other items throughout the project's life.

Specifically, the columns identify the major activities such as initial construction, reconstruction, replacement, maintenance, and rehabilitation that reflect the total long-term project costs for each activity over the forty-year project's life. The rows represent the cumulative cost of all activities including maintenance, rehabilitation and replacement for each year of the project's 40-year life. These costs represent the total project cost, as well as the incremental cost over and beyond that

of the original project. The shaded columns indicate the total project cost for each relevant activity. The un-shaded columns reflect the incremental cost over those of the original project.

Based on the suggested methodology, only those improvements in excess of those already present should be accounted for. For example, if an existing roadway or bridge surface is expanded from 28 feet to 48, feet then approxiametly 42% of the long-term projects cost for maintenance, rehabilitation and reconstruction costs should be identified by year of occurrence and accounted for as a long-term project cost. Similarly, if a Variable Message Sign (VMS) Overhead is installed as part of a project, preventative maintenance, routine maintenance, corrective maintenance, and replacement costs should be identified by year of occurrence and accounted for as a long-term project cost. The sum of these incremental costs reflects a financial obligation over and beyond that required of the existing facility.

Table 1-**Constant 2005 Dollars** and Table 2-**Year of Expenditure Dollars** represents a $10 million roadway or bridge project that rebuilds the existing roadway surface from 28 foot to 48 foot. It also includes the installation of a VMS Overhead sign. The roadway surface will be totally reconstructed in 40 years and the VMS Overhead sign will be replaced every ten years at a cost of approxiametly $100,000 or approxiametly four times over the project's life. Maintenance activities will include not only roadway surface or bridge maintenance but also the preventative, routine, and corrective maintenance related to keeping the VMS Overhead sign operational over the project's life. Rehabilitation costs for this project in the form of major resurfacing are scheduled at ten-year intervals at a cost of $4,300,000 in 2005 constant dollars.

From a reconstruction perspective, only incremental costs will be calculated. Based on the above example, approxiametly 42% of the future year reconstruction cost of the facility would be considered an incremental cost. However, since the ITS VMS Overhead sign was not originally a component of the existing project, the full replacement costs for each sign would be included as an incremental long-term project cost.

Maintenance costs for roadway surface and bridge maintenance would be developed similar to the proposed calculation method proposed for reconstruction with the incremental cost of roadway or bridge maintenance being approxiametly 42%. For example, based on $9,500 per lane mile for maintenance activities, a 48-foot roadway would require about $38,000 per year in *2005 constant dollars*. However, the existing facility would absorb $22,167 of the $38,000 leaving an incremental maintenance cost of $15,833 attributable to adding capacity to the original asset. ITS routine, preventative and corrective maintenance costs, however, would fully be accounted for as incremental project costs because they were not features of the existing project.

Rehabilitation costs associated with roadway surface or bridges should be calculated similar to reconstruction and maintenance costs by applying the 42% factor that represents the incremental increase over the existing facility.

Year of Expenditure Dollars would reflect the cost including inflation based on a trend analysis of the dataset for each activity.

The following tables represent both the full project costs as well as the incremental costs associated with the proposed project. They reflect a method and do not necessarily represent true costs for construction, reconstruction, maintenance or rehabilitation activities. What the tables do show is a way to gain a better grasp of long-term costs not normally reflected in project development. From this hypothetical example, **Table 1-Constant 2005 Dollars** reflects a forty-year total project cost, including annual roadway maintenance, ITS acquisition and maintenance, and roadway rehabilitation of $19.1 million with $8.2 million attributable to incremental costs associated with maintenance, ITS and rehabilitation activities. **Similarly, Table 2-Year of Expenditure Dollars** reflects a forty-year total project cost, including annual roadway maintenance, ITS acquisition and maintenance, and roadway rehabilitation of $72.4 million with

$31.4 million attributable to incremental costs associated with maintenance, ITS and rehabilitation activities

Table 1. Constant 2005 Dollars

Year	Initial Construction	ITS Acquisition and Maintenance	Roadway Maintenance	Incremental Maintenance	Rehabilitation	Incremental Rehabilitation	Total Cost (Including Incremental)	Incremental Cost Total
0	10,000,000			-				-
1		500	38,000	15,833			38,500	16,333
2		500	38,000	15,833			38,500	16,333
3		500	38,000	15,833			38,500	16,333
4		500	38,000	15,833			38,500	16,333
5		500	38,000	15,833			38,500	16,333
6		500	38,000	15,833			38,500	16,333
7		500	38,000	15,833			38,500	16,333
8		500	38,000	15,833			38,500	16,333
9		500	38,000	15,833			38,500	16,333
10		100,500	38,000	15,833	4,300,000	1,791,667	4,438,500	1,908,000
11		500	38,000	15,833			38,500	16,333
12		500	38,000	15,833			38,500	116,333
13		500	38,000	15,833			38,500	16,333
14		500	38,000	15,833			38,500	16,333
15		500	38,000	15,833			38,500	16,333
16		500	38,000	15,833			38,500	16,333
17		500	38,000	15,833			38,500	16,333
18		500	38,000	15,833			38,500	16,333
19		500	38,000	15,833			38,500	16,333
20		100,500	38,000	15,833	4,300,000	1,791,667	4,438,500	1,908,000
21		500	38,000	15,833			38,500	16,333
22		500	38,000	15,833			38,500	116,333
23		500	38,000	15,833			38,500	16,333
24		500	38,000	15,833			38,500	16,333
25		500	38,000	15,833			38,500	16,333
26		500	38,000	15,833			38,500	16,333
27		500	38,000	15,833			38,500	16,333
28		500	38,000	15,833			38,500	16,333
29		500	38,000	15,833			38,500	16,333
30		100,500	38,000	15,833	4,300,000	1,791,667	4,438,500	1,908,000
31		500	38,000	15,833			38,500	16,333
32		500	38,000	15,833			38,500	16,333
33		500	38,000	15,833			38,500	16,333
34		500	38,000	15,833			38,500	16,333
35		500	38,000	15,833			38,500	16,333
36		500	38,000	15,833			38,500	16,333
37		500	38,000	15,833			38,500	16,333
38		500	38,000	15,833			38,500	16,333
39		500	38,000	15,833			38,500	16,333
40		100,500	38,000	15,833	4,300,000	1,791,667	4,438,500	1,908,000
Total	**10,000,000**	**420,000**	**1,520,000**	**633,320**	**17,200,000**	**7,166,668**	**19,140,000**	**8,219,988**

Assumptions:

Initial construction costs are not included in the life cycle cost analysis.
All costs in 2005 Dollars
Incremental Project costs equals 42% of total project costs.

Table 2. Year of Expenditure Dollars

Year	Initial Construction	ITS Acquisition and Maintenance	Roadway Maintenance	Incremental Maintenance	Rehabilitation	Incremental Rehabilitation	Total Cost (Including Incremental)	Incremental Cost Total
0	10,000,000							-
1		500	39,140	16,308			39,640	16,808
2		500	40,314	16,797			40,814	17,297
3		500	41,524	17,301			42,024	17,801
4		500	42,769	17,820			43,269	18,320
5		500	44,052	18,355			44,552	18,855
6		500	45,374	18,905			45,874	19,405
7		500	46,735	19,473			47,235	19,973
8		500	48,137	20,057			48,637	20,557
9		500	49,581	20,658			50,081	21,158
10		179,085	51,069	21,278	7,004,247	2,918,436	7,234,401	3,118,799
11		500	52,601	21,917			53,101	22,417
12		500	54,179	22,574			54,679	23,074
13		500	55,804	23,251			56,304	23,751
14		500	57,478	23,949			57,978	24,449
15		500	59,203	24,667			59,703	25,167
16		500	60,979	25,407			61,479	25,907
17		500	62,808	26,170			63,308	26,670
18		500	64,692	26,955			65,192	27,455
19		500	66,633	27,763			67,133	28,263
20		320,714	68,632	28,596	11,409,160	4,753,825	11,798,506	5,103,135
21		500	70,691	29,454			71,191	29,954
22		500	72,812	30,338			73,312	30,838
23		500	74,996	31,248			75,496	31,748
24		500	77,246	32,185			77,746	32,685
25		500	79,564	33,151			80,064	33,651
26		500	81,950	34,145			82,450	34,645
27		500	84,409	35,170			84,909	35,670
28		500	86,941	36,225			87,441	36,725
29		500	89,549	37,312			90,049	37,812
30		574,349	92,236	38,431	18,584,352	7,743,480	19,250,937	8,356,260
31		500	95,003	39,584			95,503	40,084
32		500	97,853	40,771			98,353	41,271
33		500	100,789	41,994			101,289	42,494
34		500	103,812	43,254			104,312	43,754
35		500	106,927	44,552			107,427	45,052
36		500	110,135	45,888			110,635	46,388
37		500	113,439	47,265			113,939	47,765
38		500	116,842	48,683			117,342	49,183
39		500	120,347	50,144			120,847	50,644
40		1,028,572	123,957	51,648	30,271,951	12,613,313	31,424,480	13,693,533
Total	**10,000,000**	**2,120,720**	**2,951,205**	**1,229,644**	**67,269,710**	**28,029,054**	**72,341,635**	**31,379,418**

Assumptions:

Initial construction costs are not included in the life cycle cost analysis.
All Costs in Year of Expenditure Dollars
Annual Construction Increase = 5%
Annual Maintenance Increase = 3%
Annual Rehabilitation Increase = 5%
Incremental Project costs equals 42% of total project costs.

8. Conclusions and Recommendations

This section of the report will summarize the types of data necessary to calculate a project's long-term costs and to identify gaps in the existing data sets that need to be remedied. The long-term cost is defined as those costs incurred subsequent to those associated with the projects initial construction cost including maintenance, rehabilitation, and reconstruction/replacement costs. Specific features and activities include not only pavement and bridge construction, but also activities that enhance mobility, safety and visual aesthetics. Historically, these costs have not been major considerations in deciding whether a project would advance or not. However, due to limited financial resources, the long-term consequences of adding additional capacity to the state highway system will put increasing pressures on future year budgets.

At present, there is no central repository of data that would facilitate the development of long-term project's cost. Available data is housed in the various CDOT branches and not necessarily collected in a consistent or readily useable or accessible manner.

Currently, data on surface related activities, bridge, ITS and maintenance is accessed manually from each branch within CDOT. An individual attempting to compile information on the long-term costs associated with a project currently has to manually collect the data from each CDOT Branch.

CDOT has a long history of collecting pavement related history through its Pavement Management System. This data is used in developing project level Life Cycle Cost Analysis. The data allows for the development of long-term cost analysis and timing of activities for maintenance, rehabilitation and reconstruction/replacement activities at the CDOT region, county and route and reference point specific level.

Unfortunately, a similar level of analysis for bridge related life cycle cost analysis is currently not being performed by CDOT. However, bridge staff have indicated that over the next two years that PONTIS, the CDOT bridge management system, will be employed and when populated with sufficient data will generate information relating to costs and timing of activities for maintenance (now covered under the Structures MPS in the maintenance budget), rehabilitation, and reconstruction/replacement costs by specific location.

Based on the Performance Budgeting System for Maintenance costs are currently tracked under the nine MPAs under which over fifty specific maintenance activities are subsumed. This information is collected at the CDOT region, county and reference point specific level.

ITS is currently developing a reporting system that will allow for the development of life cycle cost analysis based on maintenance and replacement costs for over 30 ITS applications. Specific maintenance activities include prevention, routine, corrective and replacement activities. However, the reporting system is currently not sufficiently populated for all ITS applications to perform Life Cycle Cost Analysis. It is envisioned that the collection of information will be initiated shortly and that Life Cycle Costs for each ITS application will be generated as the reporting system comes on line and is populated with sufficient data.

CDOT's current goal is to develop a reporting system that will be a central repository of all data relating to project development. The system will track various activities including construction cost information, maintenance related activities, rehabilitation activities, and reconstruction/replacement activities for all transportation related features related to a project's cost. Once sufficient information is collected for each activity, it will be possible to project future year costs for each activity down to the CDOT region level, county and reference point specific level.

The most noticeable data gaps in developing comprehensive long-term project costs are related to ITS and bridge. As previously mentioned, the ITS group is currently developing a reporting system that will allow for the development of life cycle cost analysis based on maintenance and replacement costs for over 30 ITS applications. This reporting system is consistent with and will interface with the current CDOT effort to provide a central repository of data related to project and repair activities. As relates to bridges, PONTIS, the bridge management system should be reconfigured to interface with the current CDOT effort to provide a central repository of data for project and repair activities.

Implementing this centralized data set can be accomplished in two phases. The first phase would identify a comprehensive list of all features necessary to capture all costs associated with a project including initial cost, maintenance, rehabilitation and reconstruction/replacement over the projects life. This information would be collected at the CDOT region level, county and reference point specific level. The second phase would populate the data fields with sufficient data to allow for the development of cost estimates and the intervals for performing various activities.