Project No. NCHRP 14-27A **COPY NO. _**

IMPLEMENTATION OF REPORT 816: A GUIDE FOR THE PRESERVATION OF HIGHWAY TUNNEL SYSTEMS

FINAL REPORT

Prepared for

National Cooperative Highway Research Program

Transportation Research Board

of

The National Academies of Sciences, Engineering, and Medicine

Gannett Fleming, Inc.
Camp Hill, PA

March 2019

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CHAPTER 1

Background

Tunnel owners today are faced with aging tunnel assets and increasingly limited funding for the maintenance and preservation of their tunnels and associated systems. Prioritizing maintenance and preservation implementation is complicated, especially considering the complex systems comprising tunnels and that tunnel preservation often competes with other transportation elements, such as bridges and pavement, for available funding. In addition, several owners' maintenance staff who are knowledgeable about tunnel system maintenance are nearing retirement, leaving a new regime of inexperienced staff with minimal documentation regarding what is needed to maintain and improve their tunnels, at a critical time when tunnel asset management is being promoted at the federal and agency levels. For these reasons, *Report 816: A Guide for the Preservation of Highway Tunnel Systems* (NCHRP 14-27) was developed to document a methodology to be used by tunnel owners to prioritize improvements to their tunnel systems.

NCHRP 14-27 was completed in July 2015 and culminated in Report 816, which was published and distributed to highway agencies across the U.S. *Report 816: A Guide for the Preservation of Highway Tunnel Systems (*Report 816*)* provides a process for tunnel asset management including a methodology using a metric to prioritize tunnel improvements across disparate systems (structural, civil, mechanical, electrical, etc.). It included an example utilizing six hypothetical preservation actions and detailed the process of developing an initial priority, adjusting the priority for various reasons, and using the final priority of improvements to evaluate funding and staffing needs. While Report 816 provided detailed explanations of the use of the metric for the six preservation actions, its use with an agency owning multiple tunnels was needed to evaluate its effectiveness. This project provides a pilot to implement the methodology outlined in Report 816, to evaluate its use.

The research documented in this report is therefore a follow-up to NCHRP 14-27, implementing the process proposed in Report 816 in a pilot project with state Department of Transportation (DOT) tunnel owners. The objective of this pilot project is two-fold: 1) to test the use of Report 816 methodology for prioritizing tunnel improvements, working with agencies using their real world conditions and tunnel improvements, and to document potential improvements and areas for future research; and 2) to train agencies in the interpretation and application of Report 816 to assist in their tunnel management. Two different implementations are documented in this report: the first is with Colorado Department of Transportation (CDOT) and the second is with a group of multiple agencies. In the first pilot, the metric that was developed and documented in Report 816 was utilized to prioritize improvements for 22 tunnels for CDOT. A one and one-half day workshop was held with the CDOT Agency Asset Management Team (AAMT) on May 30 and 31, 2018. This report documents the preparations for, and the AAMT workshop, as well as findings from the pilot project. The second pilot - a similar workshop with a mock AAMT consisting of multiple agency personnel was held February 26, 2019 in Washington, DC. Representatives from Virginia DOT (VDOT), Maryland Transportation Authority (MdTA), North Carolina DOT (NCDOT), Colorado DOT (CDOT), American Public Transportation Association (APTA), Washington Metropolitan Area Transit Authority (WMATA), and a representative from Transportation Technology Center in Pueblo, CO participated in the workshop. The results of this effort are also documented herein.

CHAPTER 2

Research Approach

To provide exposure to multiple agencies while also performing a detailed implementation, the pilot was crafted with two separate implementations which are documented in this report: one for a single tunnel owner with specific planned improvements, and a second one involving a group of multiple agencies, geographically separated from the first. This pilot project involves three phases as follows:

- **Phase I: Implementation Pilot with Colorado DOT** – Utilizing the recommended improvements from the recent NTIS inspections and other improvements identified by CDOT, the Report 816 methodology will be implemented in a workshop with CDOT's tunnel AAMT. This report documents the results of that implementation.
- **Phase II: Workshop with Multiple Agencies** – This workshop, to be held on the east coast, will involve personnel from multiple agencies working as a mock AAMT, to provide an introduction to the Report 816 methodology and how to implement it, and obtain a broad perspective on potential limitations of its use and areas for further research.
- **Phase III: Final Report** – The results of the entire implementation project will be documented in the Final Report.

The approach for each of the two implementations- the first with CDOT and the second with multiple agencies - are documented within this chapter in the following sections.

2.1 Pilot #1: Colorado Department of Transportation (CDOT)

The objective of the pilot project with CDOT was to implement the methodology outlined in Report 816 using tunnel improvements and preservation actions identified by CDOT for their tunnels. The pilot project can be explained in two major steps: 1) preparations for the workshop, and 2) the actual workshop with the CDOT AAMT. The elements of these steps and the approach to each are described below.

2.1.1 Preparing for the Workshop

For the workshop to be most effective, preparations were made in advance, to ensure that all critical information was available for the AAMT's use in performing the evaluation. Elements that needed to be addressed by CDOT and the research team were 1) understanding the factors that drive CDOT's decisions on asset improvements, 2) summarizing average daily traffic for each tunnel, 3) developing preservation actions and associated life cycle costs, and 4) identifying the Agency Asset Management Team (AAMT).

One of the most important preparations for the evaluation is developing an understanding of the agency's goals and objectives that drive their decision making. CDOT's Mission and Values were provided to the research team, and the team elected to discuss these further with CDOT when the AAMT convened for the workshop.

The 22 on-system tunnels owned and operated by CDOT were summarized and the Average Daily Traffic collected for each. Table 1 provides a summary of ADT for each tunnel. General tunnel configurations and locations were reviewed by the research team, and the most recent inspection reports were examined in preparation.

Table 1. Summary of Colorado Highway Tunnels

SUMMARY OF COLORADO HIGHWAY TUNNELS					
Tunnel Number	**Tunnel Name**	**Annual Average Daily Traffic**	**Year Constructed**	**Length (ft.)**	**Highway Route #**
F-13-Y	Eisenhower Tunnel (WB)	29,000	1973	8,943	I-70 WB
F-13-X	Johnson Tunnel (EB)	29,000	1979	8,961	I-70 EB
F-15-DM	Veterans Memorial (WB)	49,000	1961	819	I-70 WB
F-15-DN	Veterans Memorial (EB)	49,000	1961	749	I-70 EB
L-06-P	Bear Creek	2,200	1901	125	Lower Gold Camp Rd.
N-09-F	Wolf Creek	3,200	2002	1,026	CO 160
F-07-Q	No Name (WB)	15,000	1964	1,046	I-70 WB
F-07-R	No Name (EB)	15,000	1964	1,046	I-70 EB
F-08-AT	Reverse Curve	14,000	1989	582	I-70
F-15-AY	Clear Creak No. 1	11,000	1951	883	CO 6
F-15-AX	Clear Creek No. 2	11,000	1941	1,068	CO 6
F-15-AW	Clear Creek No. 3	11,000	1957	769	CO 6
F-15-Y	Clear Creek No. 5	4,200	1939	411	CO 6
F-15-X	Clear Creek No. 6	4,200	1939	590	CO 6
H-03-BT	Beavertail (WB)	16,000	1983	675	I-70 WB
H-03-BU	Beavertail (EB)	16,000	1983	684	I-70 EB
B-15-E	Mishawaka	1,200	1929	95	CO 14
D-15-AS	Boulder Canyon	3,900	1953	350	CO 119
F-08-AP	Hanging Lake (EB)	14,000	1992	3,902	I-70 EB
F-08-AQ	Hanging Lake (WB)	14,000	1992	3,863	I-70 WB
D-01-CC-185	Speer Blvd	24,609	1995	710	Speer Blvd
D-27-MP-220	Red Rocks	665	1940	56	Red Rocks Park Rd.

To develop tunnel preservation actions, CDOT utilizes a system based on deterioration modeling where needed improvements are identifed based on service life and condition. Conditions are updated on a biennial basis using the results of inspections as well as operator input. The model forecasts improvement projects for a two year period; the improvements forecast for the workshop were for the two year period of fiscal years 2021 and 2022, which was budgeted for $20M. From this approach, a listing of preservation actions was developed, and ball park life cycle costs were established for each. A listing of the proposed

preservation actions is included in Appendix A along with a description of each improvement. An abbreviated list showing six projects is included in Table 2.

Table 2. Preservation Actions

Preservation Action	Tunnel Name	Project Description
Fan Motor Modification/Replacement-Electrical	Johnson Tunnel	Rebuilding fan motors, installing new VFDs, and associated electrical improvements.
Tunnel Ops	Beavertail	Replacement of cameras for both tunnels, and fiber connection to primary control room, which is located at HLT, is needed.
Shotcrete/Concrete Liner Repair	Clear Creek	Water intrusion and past flooding resulted in voids behind liner; curtain grouting is required.
VMS Replacement	Johnson Tunnel	Replacement of Variable Message Signs due to collision.
LED Lighting Replacement	EJMT	Replacement of lighting system in both tubes with LED lighting since replacement parts for existing system are no longer available.
Emergency Generator Replacement	HLT	Replacement of existing undersized emergency generator.

Finally, CDOT identified their Agency Asset Management Team, which consisted of their statewide Tunnel Asset Manager, Region 1 West Tunnel Program Engineer, operators for two of their complex tunnels (Hanging Lakes and Eisenhower Johnson Memorial Tunnel), and four asset management staff either supporting the project or leading asset management for other highway assets such as bridges. This group met for many weeks in advance of the workshop to discuss the planned approach and to gather the necessary information to support the workshop.

2.1.2 The Workshop

The workshop was planned for one and one-half days, to allow for a review of the Report 816 prioritization methodology on Day 1, which would prepare the attendees for the process to follow on Day 2.

On the first day, following introductions of those present, the research team provided an overview of the tunnel asset management process, which utilizes the NTIS tunnel inspection results and operator input to develop preservation actions, and walked through step-by-step the use of the metric to establish a priority for a sampling of tunnel system improvements. A significant amount of time was spent discussing agency Levels of Service (LOS).

2.1.2.1 Levels of Service (LOS)

A critical step in the process, the LOS need to be established to initiate the evaluation which was set to begin on Day 2. It was noted that CDOT is currently addressing the development of systemwide goals and objectives. At the time of the workshop, the goals were reflected in the agency mission statement and values as noted below.

CDOT MISSION STATEMENT

The mission of the Colorado Department of Transportation is to provide the best multi modal transportation system for Colorado that most effectively moves people, goods, and information.

CDOT VALUES

Safety – We work and live safely! We protect human life, preserve property, and put employee safety before production.
People – We value our employees! We acknowledge and recognize the skills and abilities of our coworkers, place a high priority on employee safety, and draw strength from our diversity and commitment to equal opportunity.
Integrity – We earn Colorado's trust! We are honest and responsible in all that we do and hold ourselves to the highest moral and ethical standards.
Customer Service – We satisfy our customers! With a can-do attitude we work together and with others to respond effectively to our customer's needs.
Excellence – We are committed to quality! We are leaders and problem solvers, continuously improving our products and services in support of our commitment to provide the best transportation systems for Colorado.
Respect – We respect each other! We are kind and civil with everyone, and we act with courage and humility.

There was much discussion of how to apply the current values to tunnels in a meaningful way to aid in prioritizing tunnel improvements. Discussions with the AAMT ultimately centered around LOS such as safety, mobility, user experience, infrastructure condition, economic vitality, historical impacts, environmental, and security. After much discussion, the AAMT resolved to move forward with the following LOS for the workshop:

- Economic Vitality – This LOS recognizes that Colorado tunnels are critical to the economic vitality of the state, providing a $1B/yr economic driver. The intent of this LOS was to reward projects at the remote tunnels that provide access to truckers and tourists traveling across the state.
- Safety – The tunnel and its systems are safe for the traveling public as well as for workers who perform maintenance and repairs.
- Mobility/Quality of Service – This LOS reflects the desire to improve and maintain customer service. It is the ability to maintain traffic and the mobility of users through the tunnel, and to provide comfortable travel in terms of ride, visibility, aesthetics, and environment.
- Preservation – The condition and remaining life of the tunnel elements allow the tunnel to function well into the future.

- Environment – The absence of negative impacts on the environment as a result of the tunnel and its systems.
- Security – The tunnel is secure from technological or natural hazards.

Once the LOS were agreed to by the AAMT, relative weights were assigned. This was accomplished by initially ranking the LOS from 1 to 6, and then distributing weights according to their rank. The resulting ranks and weights are shown in Table 3.

Table 3. Colorado Levels of Service and Relative Weights

COLORADO LEVELS OF SERVICE FOR TUNNELS		
Rank	**Level of Service**	**Weight**
1	Preservation	30%
2	Mobility/Quality of Service	25%
3	Safety	20%
4	Economic Vitality	15%
5	Security	5%
6	Environment	5%

Day 1 concluded with the development of the LOS.

On Day 2 of the tunnel prioritization workshop, the AAMT began by evaluating each proposed preservation action for its impact on the LOS. Each preservation action was presented by the tunnel operators or other individuals on the AAMT, describing the improvement and its need or objective. The AAMT then assessed each, one by one, assigning a rating between 1 and 5 as indicated in Figure 1.

Figure 1. LOS Ratings

LOS 1 The improvement ***will have very little impact*** in improving the performance associated with the LOS.

LOS 5 The improvement ***will greatly impact*** the performance associated with the LOS in a positive way.

* LOS Rating = 0 if Not Applicable N/A

The LOS Scoring for the first six preservation actions, of the entire listing of 37 that were evaluated, are shown in Table 4 below. The LOS evaluation of the entire listing of preservation actions that were reviewed is included in Appendix A.

Table 4. LOS Scores

LEVEL OF SERVICE SCORE								
	Level of Service	Preservation	Mobility/ Quality of Service	Safety	Economic Vitality	Security	Environment	Score
	Weight	30	25	20	15	5	5	100
Preservation Action	Tunnel							
Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	4	0	4	0	0	4	**44.0**
Tunnel Ops	Beavertail	5	2	3	0	4	0	**56.0**
Shotcrete/Concrete Liner Repair	Clear Creek	4	4	5	4	0	0	**76.0**
VMS Repair/Replace due to Impact	Johnson Tunnel	5	5	5	1	0	0	**78.0**
LED Lighting Replacement	EJMT	5	4	4	2	1	3	**76.0**
Emergency Generator Replacement	HLT	3	0	5	0	1	0	**39.0**

The first preservation action is for installation of variable frequency drives on the fans at Eisenhower Johnson Memorial Tunnel (EJMT), which would provide better operational control, and would allow fans to be started more quickly during a fire scenario. VFDs would also result in lower energy useage, since fans ramp up slowly to full speed. For these reasons, fan motor modification received a 4 for preservation, safety, and environment. The other LOS were not applicable and received a 0.

The remaining preservation actions were discussed and evaluated in a similar fashion. The complete table is included in Appendix A.

2.1.2.2 Cost Effectiveness (CE)

Cost effectiveness was evaluated using the average daily traffic values in Table 1 to reflect the number of users impacted by a given preservation action, and the estimated life cycle costs developed for each of the preservation actions. As explained in Report 816, the CE Score uses the inverse of the cost per user, and applies a Cost Factor, F. The value of F is adjusted to provide meaningful scores that:

- Are distributed relatively evenly from 0 to 100.
- Prevent too many repeat scores of 0 or 100.
- Properly reward actions that have low capital costs and affect a large number of vehicles.

An initial Cost Factor equal to 10 was utilized, but this resulted in almost all scores falling between 0 and 35. To gain a better distribution, alternative cost factors were considered ; 1, 2.5, 5, 10, 20, 50 and 100 were all plotted to view the resulting distribution. The AAMT and research team felt that the best distribution was obtained utilizing F=2.5. Figure 2 shows the CE Score data points plotted for various values of F ranging from 1 to 100.

The evaluation proceeded, and the results were reviewed for reasonableness. The resulting CE Scores for the first six preservation actions are provided in Table 5; the full listing is provided in Appendix A.

Figure 2. Scatter Plot of CE Scores Using Various Values for F, Cost Factor

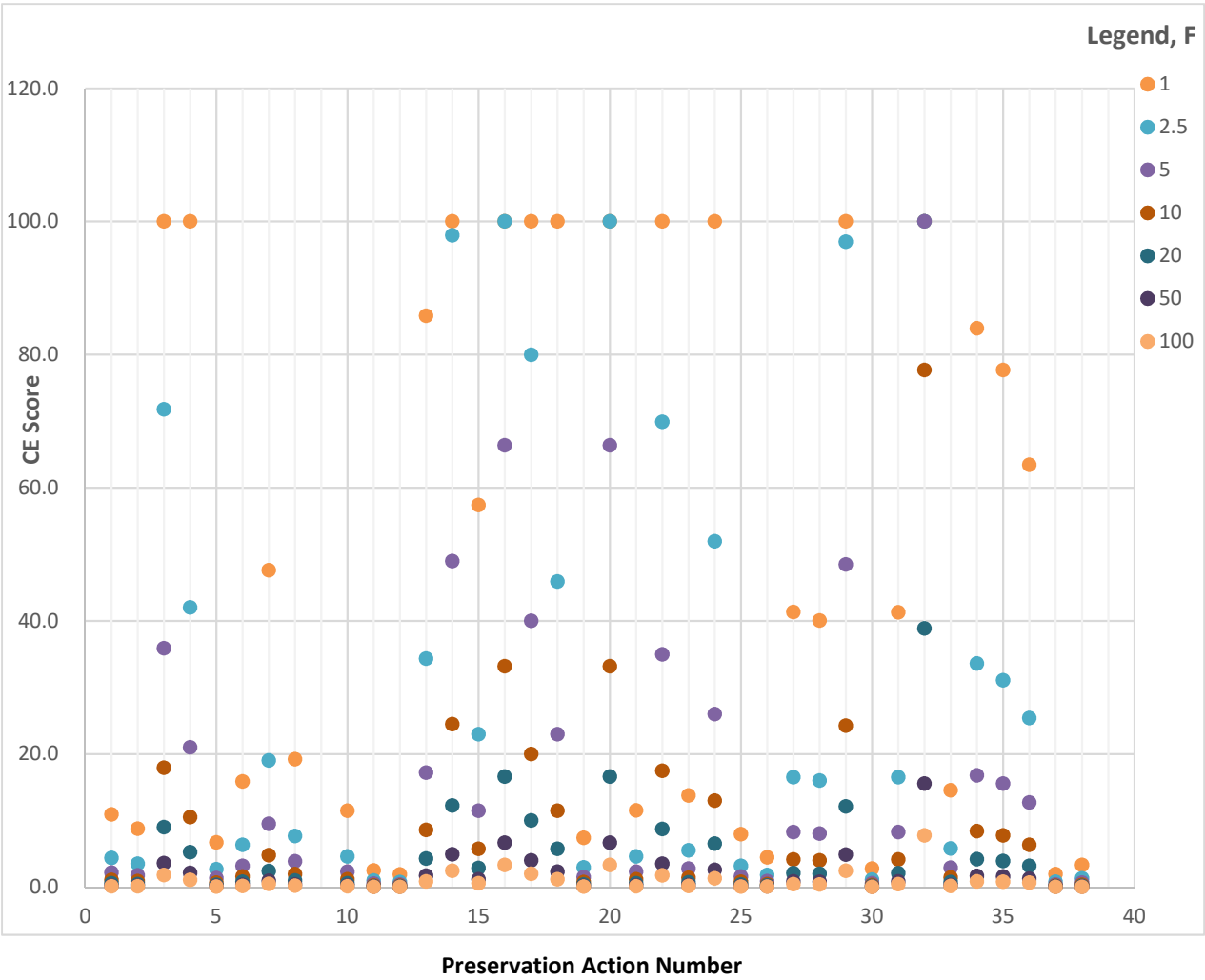

Table 5. CE Scores

COST EFFECTIVENESS SCORE										
Preservation Action	**Tunnel**	**Capital Cost**	**Agency Oversight Cost**	**Annual Change in Costs**	**PV of LCC**	**Rem'g Life due to Preserv. Action**	**ADT (x 1000)**	**Annualized Life Cycle Cost**	**Annual Cost per Daily Vehicle**	**Score**
Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	$ 4,500,000	$ 1,350,000	$ (120,000)	$ 3,076,227	40	15	$133,085	$ 9.18	**4.4**
Tunnel Ops	Beavertail	$ 100,000	$ 30,000		$ 130,000	10	16	$15,240	$ 0.95	**42.0**
Shotcrete/Concrete Liner Repair	Clear Creek	$ 17,183,500	$ 5,155,050		$ 22,338,550	50	29	$868,199	$ 29.94	**1.3**
VMS Repair/Replace due to Impact	Johnson Tunnel	$ 1,045,000	$ 313,500		$ 1,358,500	20	15	$91,313	$ 6.30	**6.4**
LED Lighting Replacement	EJMT	$ 15,000,000	$ 4,500,000	$ (140,000)	$ 17,417,154	20	29	$1,170,706	$ 40.37	**1.0**
Emergency Generator Replacement	HLT	$ 3,500,000	$ 1,050,000	$ (20,000)	$ 4,087,705	40	14	$176,844	$ 12.63	**3.2**

2.1.2.3 Risk Based Urgency (RBU)

The evaluation continued, considering condition, remaining life, risks and other considerations (i.e. regulatory). Many preservation actions were indicated to be driven by regulatory compliance, primarily those related to NFPA 502; another needed improvement that had a regulatory component was the water treatment plant upgrades at EJMT.

Table 6. RBU Scores

RISK-BASED URGENCY SCORE									
Preservation Action	**Tunnel**	**Remaining Life**	**Asset's Theoretical Service Life**	**% Life Expended**	**Condition (1=Good, 4=Severe)**	**Regulatory Compliance Issue? (Y/N)**	**Risk of Unplanned Event (1=Low, 3=High)**	**Risk-Based Urgency (1 to 10)**	**Risk-Based Urgency Score**
Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	12	50	76.0	3	Y	3	8	**80.0**
Tunnel Ops	Beavertail	0	10	100.0	4	Y	3	9	**90.0**
Shotcrete/Concrete Liner Repair	Clear Creek	19	85	77.6	4	N	3	8	**80.0**
VMS Repair/Replace due to Impact	Johnson Tunnel	0	20	100.0	4	Y	3	9	**90.0**
LED Lighting Replacement	EJMT	4	20	80.0	2	Y	2	8	**80.0**
Emergency Generator Replacement	HLT	14	40	65.0	1	Y	3	8	**80.0**

2.1.2.4 Overall Measure of Effectiveness (MOE) and Calculated Priority

To combine the three scores -- LOS, CE, and RBU-- to get the calculated priority for preservation actions, the AAMT was asked to put a weight on the three scores. CDOT considered the three scores and ultimately elected to use the following weighting:

LOS Score – 35%
CE Score – 20%
RBU Score – 45%

These weights were used to calculate the overall MOE and led to the calculated priority shown in Table 7. The full prioritization is in Appendix A; only the first six preservation actions and their priority among the 37 improvement projects is shown.

Table 7. Overall Measure of Effectiveness and Calculated Priority

OVERALL MEASURE OF EFFECTIVENESS						
	Weight	35	20	45	100	
Preservation Action	**Tunnel**	**Levels of Service Score**	**Cost Effectiveness Score**	**Risk Based Urgency Score**	**Total Score**	**Calculated Priority**
Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	44.0	4.4	80.0	**52.3**	23
Tunnel Ops	Beavertail	56.0	42.0	90.0	**68.5**	11
Shotcrete/Concrete Liner Repair	Clear Creek	76.0	1.3	80.0	**62.9**	15
VMS Repair/Replace due to Impact	Johnson Tunnel	78.0	6.4	90.0	**69.1**	9
LED Lighting Replacement	EJMT	76.0	1.0	80.0	**62.8**	16
Emergency Generator Replacement	HLT	39.0	3.2	80.0	**50.3**	27

Given that RBU is weighted the highest, it is reasonable that the higher RBU Scores received the highest ranks of these projects. Coupled with the next highest weight applied to the LOS Score, the projects with high scores for both RBU and LOS were ranked the highest. The CE Score had relatively little impact, and the CE Scores were all relatively low, despite the attempt to create good variability through the use of the Cost Factor. For further discussion on CE Scores see Chapter 3.

2.1.2.5 User Priority and Funding

The calculated priority provides a preliminary estimation based on the rational approach inherent in the metric, but the final priority must be determined by each agency. One factor that might influence priorities is the impact on the traveling public. Activities that require tunnel lane closures for an extended period of time may be grouped with other activities within the same tunnel that can be accomplished during the same service outage. There are many factors that go into an owner's ultimate decision on priorities, but the MOE methodology presented above provides a first pass that can assist an owner in making decisions.

CDOT did not make significant changes to the calculated priority. The AAMT elected to group projects related to liner repairs in the six Clear Creek Tunnels in the same funding year. Tunnel lighting projects were also grouped to allow them to be let in one contract for these tunnels. To establish the prioritization, it became evident that the funding evaluation should occur simultaneously when deciding the agency priority. With a budget of approximately $20M for the years 2020 and 2021, CDOT shifted some projects to fit within the two year budget. This often meant increasing the priority of a lower cost option. The CDOT user priority is shown in Table 8, along with the funding evaluation. The cumulative costs shown on the right reflect all projects within the year listed. This is shown in the full listing in Appendix A (Table A.6).

Table 8. Prioritization and Funding

PRIORITIZATION and FUNDING											
Preservation Action	Tunnel	Total Score	Calculated Priority	User Priority	Capital Cost	Agency Oversight	Subtotal Cost	Funding Year (1+)	Escalation	Total Cost	Cumulative Cost
VMS Repair/Replace due to Impact	Johnson Tunnel	**69.1**	9	10	$ 1,045,000	$ 313,500	$ 1,358,500	1	$ -	$ 1,358,500	$ 1,358,500
Tunnel Ops	Beavertail	**68.5**	11	11	$ 100,000	$ 30,000	$ 130,000	1	$ -	$ 130,000	$ 1,488,500
LED Lighting Replacement	EJMT	**62.8**	15	15	$ 15,000,000	$ 4,500,000	$ 19,500,000	2	$ 585,000	$ 20,085,000	$ 20,085,000
Shotcrete/Concrete Liner Repair	Clear Creek			17	$ 17,183,500	$ 5,155,050	$ 22,338,550	4	$ 2,071,387	$ 24,409,937	$ 24,409,937
Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	**52.3**	22	24	$ 4,500,000	$ 1,350,000	$ 5,850,000	6	$ 931,753	$ 6,781,753	$ 6,781,753
Emergency Generator Replacement	HLT	**50.3**	26	27	$ 3,500,000	$ 1,050,000	$ 4,550,000	6	$ 724,697	$ 5,274,697	$ 12,056,450

2.2 Pilot #2: Workshop with Multiple Agencies

In the second workshop, which was held February 26, 2019 in Washington, DC, multiple agencies participated as a mock agency asset management team (AAMT) to prioritize the improvements for the Colorado tunnels established in Pilot #1. The objective of this pilot was to engage several agencies, this time on the east coast, to familiarize them with the Report 816 methodology for prioritizing improvements, and to evaluate the process. The preparations for the workshop, the actual working session, and the conclusions are described below.

2.2.1 The Workshop

The workshop began with introductions of those present, and then the research team provided an overview of the tunnel asset management process, which utilizes the NTIS tunnel inspection results and operator input to develop preservation actions, and walked through step-by-step the use of the metric to establish a priority for a sampling of tunnel system improvements.

Workshop #2 utilized the data from the pilot with Colorado Department of Transportation (CDOT) as the basis for the prioritization. The 22 on-system tunnels owned and operated by CDOT, along with the Average Daily Traffic for these tunnels (see Table 1) were reviewed by the group. Steve Harelson of CDOT provided a general description to characterize each tunnel and explained the significance of the I-70 corridor to the economy of Colorado, as a major east-west link for truck commerce and for tourists accessing the many ski resorts.

2.2.1.1 Levels of Service (LOS)

Rather than utilizing the Levels of Service (LOS) that were selected by CDOT in the first pilot (Workshop #1), the group discussed and selected the LOS to be used for the prioritization. Among the goals discussed were:

- Safety
- Availability of Funding for Tunnels
- Preservation
- Customer Service/Reliability
- Reduction in Traffic
- Security
- Environment
- Maintaining Standards
- Reduced Maintenance Costs

Ultimately, the goals that were selected for the prioritization were very similar to CDOT's in Workshop #1, though the relative weights varied somewhat (see Table 9):

- Safety - The tunnel and its systems are safe for the traveling public as well as for workers who perform maintenance and repairs.
- Customer Service/Reliability - The desire to improve and maintain customer service. It is the ability to maintain traffic and the mobility of users through the tunnel, and to provide comfortable travel in terms of ride, visibility, aesthetics, and environment.

- Preservation - The condition and remaining life of the tunnel elements allow the tunnel to function well into the future.
- Reduced Maintenance – With the high cost of maintenance, it is desirable to find ways to reduce tunnel maintenance for the future.

Table 9. Workshop #2 Levels of Service and Relative Weights

COLORADO LEVELS OF SERVICE FOR TUNNELS		
Rank	**Level of Service**	**Weight**
1	Safety	40%
2	Customer Service/Reliability	30%
3	Preservation	20%
4	Reduced Maintenance	10%

The preservation actions that were developed in the pilot project with CDOT (see Table 2) were also utilized in the prioritization in Workshop #2. Each proposed preservation action was initially described and discussed, followed by an evaluation of its impact on the LOS. The AAMT then assessed each, one by one, assigning a rating between 1 and 5, where 1 has little impact on the LOS and 5 has high impact on the LOS.

The LOS Scoring for the preservation actions that were addressed in the second workshop are shown in Table 10 below.

Table 10. LOS Scores

LEVEL OF SERVICE SCORE						
	Level of Service	Safety	Customer Service/ Reliability	Preservation	Reduced Maintenance	Score
	Weight	40	30	20	10	100
Preservation Action	Tunnel					
Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	4	2	5	3	**70.0**
Roof Replacement Project	EJMT	1	0	5	4	**36.0**
Tunnel Ops	Beavertail	4	2	5	1	**66.0**
Shotcrete/Concrete Liner Repair	Clear Creek	5	1	3	4	**66.0**
VMS Repair/Replace due to Impact	Johnson Tunnel	4	3	5	3	**76.0**
Emergency Generator Repair	Johnson Tunnel	5	5	3	1	**84.0**
Repair Plenum Drainage and Pumping Syst.	EJMT	5	1	5	4	**74.0**
Replace Wastewater Treatment Plant	EJMT	1	0	2	4	**24.0**
LED Lighting Replacement	EJMT	4	4	5	4	**84.0**
Tunnel Operations Center	EJMT	5	5	5	2	**94.0**
Replace Heat Trace with New System	EJMT	4	4	2	3	**70.0**
Liner Water Infiltration Repair	Eisenhower Tunnel	5	2	5	4	**80.0**
Emerg. Generator Replace Full KW	EJMT	5	1	5	3	**72.0**
Egress Signage	Clear Creek	4	1	0	0	**38.0**

The first preservation action is for installation of variable frequency drives on the fans at Eisenhower Johnson Memorial Tunnel (EJMT), which would allow the series of fans to be started and ramped up to full speed more quickly during a fire scenario and would thus improve safety. Since fans ramp up at a uniform pace to full speed with the addition of VFDs, as opposed to an abrupt increase to full speed without them, the reduced stress on the fans with VFDs will ultimately lead to an increase in the service life of the equipment. For these reasons, fan motor modification received a 4 for safety, and a 5 for preservation.

The replacement of the existing leaking roof on the portal building will initiate a new service life for the asset and will reduce the maintenance that has been required in recent years. For this reason the second preservation action received a 5 for preservation and a 4 for reduced maintenance.

The remaining preservation actions were discussed and evaluated in a similar fashion. Based on the selected LOS and the evaluation, the Tunnel Operations Center at EJMT received the highest LOS Score of the projects evaluated.

2.2.1.2 Cost Effectiveness (CE)

Cost effectiveness was evaluated for each preservation action as was done in Workshop #1. As with the CDOT pilot project, the Cost Factor scatter plot was reviewed and the group agreed to utilize F=2.5 for the cost effectiveness evaluation.

The evaluation proceeded, and the results were reviewed for reasonableness. The resulting CE Scores are provided in Table 11.

Table 11. CE Scores

COST EFFECTIVENESS SCORE										
Preservation Action	Tunnel	Capital Cost	Agency Oversight Cost	Annual Change in Costs	PV of LCC	Rem'g Life due to Preserv. Action	ADT (x 1000)	Annualized Life Cycle Cost	Annual Cost per Daily Vehicle	Score
Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	$ 4,500,000	$ 1,350,000	$ (120,000)	$ 4,064,703	20	15	$273,212	$ 18.84	**2.1**
Roof Replacement Project	EJMT	$ 5,000,000	$ 1,500,000		$ 6,500,000	30	29	$331,625	$ 11.44	**3.5**
Tunnel Ops	Beavertail	$ 100,000	$ 30,000		$ 130,000	10	16	$15,240	$ 0.95	**42.0**
Shotcrete/Concrete Liner Repair	Clear Creek	$ 17,183,500	$ 5,155,050		$ 22,338,550	20	11	$1,501,501	$ 136.50	**0.3**
VMS Repair/Replace due to Impact	Johnson Tunnel	$ 1,045,000	$ 313,500		$ 1,358,500	10	15	$159,258	$ 10.98	**3.6**
Emergency Generator Repair	Johnson Tunnel	$ 400,000	$ 120,000		$ 520,000	5	29	$113,544	$ 3.92	**10.2**
Repair Plenum Drainage and Pumping Syst.	EJMT	$ 2,300,000	$ 690,000	$ (50,000)	$ 2,563,490	10	29	$300,519	$ 10.36	**3.9**
Replace Wastewater Treatment Plant	EJMT	$ 4,500,000	$ 1,350,000		$ 5,850,000	50	29	$227,363	$ 7.84	**5.1**
LED Lighting Replacement	EJMT	$ 15,000,000	$ 4,500,000	$ (140,000)	$ 17,417,154	20	29	$1,170,706	$ 40.37	**1.0**
Tunnel Operations Center	EJMT	$ 10,000,000	$ 3,000,000		$ 13,000,000	15	29	$1,088,966	$ 37.55	**1.1**
Replace Heat Trace with New System	EJMT	$ 250,000	$ 75,000	$ (10,000)	$ 176,225	20	29	$11,845	$ 0.41	**97.9**
Liner Water Infiltration Repair	Eisenhower Tunnel	$ 500,000	$ 150,000		$ 650,000	20	15	$43,690	$ 3.01	**13.3**
Emerg. Generator Replace Full KW	EJMT	$ 7,000,000	$ 2,100,000		$ 9,100,000	50	29	$353,676	$ 12.20	**3.3**
Egress Signage	Clear Creek	$ 50,000	$ 15,000		$ 65,000	20	29	$4,369	$ 0.15	**100.0**

2.2.1.3 Risk Based Urgency (RBU)

The evaluation continued, considering condition, remaining life, risks and other considerations (i.e. regulatory). The remaining life and the theoretical service life, and the conditions of the assets were taken from the CDOT pilot, but the AAMT in Workshop #2 evaluated the preservation actions for regulatory compliance and risk of unplanned events. Many preservation actions were indicated to be driven by regulatory compliance, primarily for those related to NFPA 502. However, it was also noted that the electrical code has recently changed and there is need to update electrical equipment for arc flash requirements. Thus, many of the preservation actions had a regulatory compliance issue associated with it.

Based on the RBU evaluation, the highest scoring preservation actions were for the shotcrete/concrete liner repair in the Clear Creek Tunnel, which was in poor condition and near the end of its useful life. It scored a 90 for RBU, along with the plenum drainage and pumping system in the EJMT. This system is critical to pump out drainage that infiltrates the tunnel liner. A replacement of the existing system which is in severe condition is needed to avoid icicles from forming on the tunnel roof and ice from forming on the plenum floor. Table 12 provide the RBU scores for all of the preservation actions that were evaluated during the workshop.

Table 12. RBU Scores

RISK-BASED URGENCY SCORE									
Preservation Action	Tunnel	Remaining Life	Asset's Theoretical Service Life	% Life Expended	Condition (1=Good, 4=Severe)	Regulatory Compliance Issue? (Y/N)	Risk of Unplanned Event (1=Low, 3=High)	Risk-Based Urgency (1 to 10)	Risk-Based Urgency Score
Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	12	20	40.0	3	Y	3	6	**60.0**
Roof Replacement Project	EJMT	0	30	100.0	4	N	1	7	**70.0**
Tunnel Ops	Beavertail	0	10	100.0	4	Y	2	3	**30.0**
Shotcrete/Concrete Liner Repair	Clear Creek	19	20	5.0	3	N	3	9	**90.0**
VMS Repair/Replace due to Impact	Johnson Tunnel	0	10	100.0	4	Y	3	7	**70.0**
Emergency Generator Repair	Johnson Tunnel	2	10	80.0	4	Y	2	6	**60.0**
Repair Plenum Drainage and Pumping Syst.	EJMT	3	10	70.0	4	N	1	9	**90.0**
Replace Wastewater Treatment Plant	EJMT	0	50	100.0	4	Y	1	2	**20.0**
LED Lighting Replacement	EJMT	4	20	80.0	2	Y	1	7	**70.0**
Tunnel Operations Center	EJMT	5	15	66.7	2	N	3	3	**30.0**
Replace Heat Trace with New System	EJMT	0	10	100.0	3	Y	2	7	**70.0**
Liner Water Infiltration Repair	Eisenhower Tunnel	58	100	42.0	2	N	1	5	**50.0**
Emerg. Generator Replace Full KW	EJMT	2	50	96.0	3	Y	3	4	**40.0**
Egress Signage	Clear Creek	0	20	100.0	3	Y	2	8	**80.0**

2.2.1.4 Overall Measure of Effectiveness (MOE) and Calculated Priority

To combine the three scores- LOS, CE, and RBU to get the calculated priority for preservation actions, the group was asked for relative weights for the three scores. After some discussion, the AAMT elected to use the following weighting:

LOS Score – 30%
CE Score – 20%
RBU Score – 50%

These weights were used to calculate the overall MOE and led to the calculated priority shown in Table 13.

Table 13. Overall Measure of Effectiveness and Calculated Priority

OVERALL MEASURE OF EFFECTIVENESS						
	Weight	30	20	50	100	
Preservation Action	Tunnel	Levels of Service Score	Cost Effectiveness Score	Risk Based Urgency Score	Total Score	Calculated Priority
Replace Heat Trace with New System	EJMT	70.0	97.9	70.0	**75.6**	1
Egress Signage	Clear Creek	38.0	100.0	80.0	**71.4**	2
Repair Plenum Drainage and Pumping	EJMT	74.0	3.9	90.0	**68.0**	3
Shotcrete/Concrete Liner Repair	Clear Creek	66.0	0.3	90.0	**64.9**	4
LED Lighting Replacement	EJMT	84.0	1.0	70.0	**60.4**	5
VMS Repair/Replace due to Impact	Johnson Tunnel	76.0	3.6	70.0	**58.5**	6
Emergency Generator Repair	Johnson Tunnel	84.0	10.2	60.0	**57.2**	7
Liner Water Infiltration Repair	Eisenhower Tunnel	80.0	13.3	50.0	**51.7**	8
Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	70.0	2.1	60.0	**51.4**	9
Roof Replacement Project	EJMT	36.0	3.5	70.0	**46.5**	10
Tunnel Operations Center	EJMT	94.0	1.1	30.0	**43.4**	11
Tunnel Ops	Beavertail	66.0	42.0	30.0	**43.2**	12
Emerg. Generator Replace Full KW	EJMT	72.0	3.3	40.0	**42.3**	13
Replace Wastewater Treatment Plant	EJMT	24.0	5.1	20.0	**18.2**	14

Given that RBU is weighted the highest, it is reasonable that the higher RBU Scores received the highest ranks of these projects. Coupled with the next highest weight applied to the LOS Score, the projects with high scores for both RBU and LOS were ranked the highest. The CE Score had relatively little impact, due to its lower relative weight and because most of the CE Scores were low.

2.2.1.5 User Priority and Funding

Based on the first pilot with CDOT, it was determined that the user priority is most easily developed by considering the projects as initially ranked, along with the costs of each project, and determining the priority that best fits with funding. This approach is particularly helpful with a top down planning process, where a budget is established for each year and projects can be pushed up or down in the priority to fit within the available funding. Table 14 shows the results of the user priority evaluation and the initial identification of funding years for each of the first five years.

Table 14. Prioritization and Funding

PRIORITIZATION and FUNDING											
Preservation Action	Tunnel	Total Score	Calculated Priority	User Priority	Capital Cost	Agency Oversight	Subtotal Cost	Funding Year (1+)	Escalation	Total Cost	Cumulative Cost
Replace Heat Trace with New System	EJMT	75.6	1	1	$ 250,000	$ 75,000	$ 325,000	1	$ -	$ 325,000	$ 325,000
Egress Signage	Clear Creek	71.4	2	2	$ 50,000	$ 15,000	$ 65,000	1	$ -	$ 65,000	$390,000
Shotcrete/Concrete Liner Repair	Clear Creek	65.0	4	3	$ 17,183,500	$ 5,155,050	$ 22,338,550	1	$ -	$ 22,338,550	$22,728,550
Repair Plenum Drainage and Pumping Syst.	EJMT	68.0	3	4	$ 2,300,000	$ 690,000	$ 2,990,000	2	$ 89,700	$ 3,079,700	$ 3,079,700
LED Lighting Replacement	EJMT	60.4	5	5	$ 15,000,000	$ 4,500,000	$ 19,500,000	3	$ 1,187,550	$ 20,687,550	$ 20,687,550
VMS Repair/Replace due to Impact	Johnson Tunnel	58.5	6	6	$ 1,045,000	$ 313,500	$ 1,358,500	4	$ 125,970	$ 1,484,470	$ 1,484,470
Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	51.4	9	7	$ 4,500,000	$ 1,350,000	$ 5,850,000	4	$ 542,453	$ 6,392,453	$ 7,876,923
Liner Water Infiltration Repair	Eisenhower Tunnel	51.7	8	8	$ 500,000	$ 150,000	$ 650,000	5	$ 81,581	$ 731,581	$ 731,581
Roof Replacement Project	EJMT	46.5	10	9	$ 5,000,000	$ 1,500,000	$ 6,500,000				
Emergency Generator Repair	Johnson Tunnel	57.2	7	10	$ 400,000	$ 120,000	$ 520,000				
Tunnel Ops	Beavertail	43.2	12	11	$ 100,000	$ 30,000	$ 130,000				
Tunnel Operations Center	EJMT	43.4	11	12	$ 10,000,000	$ 3,000,000	$ 13,000,000				
Emerg. Generator Replace Full KW	EJMT	42.3	13	13	$ 7,000,000	$ 2,100,000	$ 9,100,000				
Replace Wastewater Treatment Plant	EJMT	18.2	14	14	$ 4,500,000	$ 1,350,000	$ 5,850,000				

2.2.1.6 Staffing

Once the User Priority and the funding years for each project are established, agency staffing needs can be considered. An estimate of agency labor must be made for each preservation action, which can then be summarized and totaled for each funding year to provide an estimate of needed agency staffing to support the tunnel improvements. Table 15 shows the results of the staffing evaluation which was discussed briefly at the workshop. The cumulative number of staff required in a given funding year is shown in the table.

Table 15. Staffing

STAFFING														
User Priority	Preservation Action	Tunnel	Total Score	Funding Year (1+)	Agency to self perform (Y/N)	Capital Cost	% Material (0 to 100) of Capital Cost	Agency Labor cost	Agency Oversight	Total Agency Labor Cost	Agency Avg. Rate ($/hr)	Agency Manhours	# of FT Staff	Cumulative # of FT Staff
1	Replace Heat Trace with New System	EJMT	75.6	1	N	$ 250,000	50	$ -	$ 75,000	$ 75,000	100	750	0.3606	0.36
2	Egress Signage		71.4	1	N	$ 50,000	25	$ -	$ 15,000	$ 15,000	100	150	0.0721	0.43
3	Shotcrete/Concrete Liner Repair	Clear Creek	65.0	1	N	$ 17,183,500	40	$ -	$ 5,155,050	$ 5,155,050	100	51,551	24.7839	25.22
4	Repair Plenum Drainage and Pumping Syst.	EJMT	68.0	2	N	$ 2,300,000	80	$ -	$ 690,000	$ 690,000	100	6,900	3.3173	3.32
5	LED Lighting Replacement	EJMT	60.4	3	N	$ 15,000,000	50	$ -	$ 4,500,000	$ 4,500,000	100	45,000	21.6346	21.63
6	VMS Repair/Replace due to Impact	Johnson Tunnel	58.5	4	N	$ 1,045,000	70	$ -	$ 313,500	$ 313,500	100	3,135	1.5072	1.51
7	Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	51.4	4	N	$ 4,500,000	20	$ -	$ 1,350,000	$ 1,350,000	100	13,500	6.4904	8.00
8	Liner Water Infiltration Repair	Eisenhower Tunnel	51.7	5	Y	$ 500,000	50	$ 250,000	$ 150,000	$ 400,000	100	4,000	1.9231	1.92
9	Roof Replacement Project	EJMT	46.5		N	$ 5,000,000	50	$ -	$ 1,500,000	$ 1,500,000	100	15,000	7.2115	
10	Emergency Generator Repair	Johnson Tunnel	57.2		N	$ 400,000	35	$ -	$ 120,000	$ 120,000	100	1,200	0.5769	
11	Tunnel Ops	Beavertail	43.2		N	$ 100,000	40	$ -	$ 30,000	$ 30,000	100	300	0.1442	
12	Tunnel Operations Center	EJMT	43.4		N	$ 10,000,000	50	$ -	$ 3,000,000	$ 3,000,000	100	30,000	14.4231	
13	Emerg. Generator Replace Full KW	EJMT	42.3		N	$ 7,000,000	50	$ -	$ 2,100,000	$ 2,100,000	100	21,000	10.0962	
14	Replace Wastewater Treatment Plant	EJMT	18.2		N	$ 4,500,000	30	$ -	$ 1,350,000	$ 1,350,000	100	13,500	6.4904	

CHAPTER 3

Findings and Applications

There are many aspects of the tunnel priorization process which warrant further evaluation and discussion. This section attempts to address the issues that arose during the workshops and provide recommendations and best practices. Key areas for discussion include:

- Preparations
- Establishing Levels of Service
- The AAMT meeting

3.1 Preparations

The AAMT meeting will be most effective if the team is prepared coming into the meeting, with the preservation actions developed, and information about each tunnel collected and available.

3.1.1 Preservation Actions

Preservation actions should include a comprehensive listing of improvements that are identified from the biennial tunnel inspections or recommended by operators or the tunnel asset manager. Preservation actions should be developed and summarized in advance of the AAMT session. Each improvement should be summarized in a table and the costs should reflect the life cycle costs associated with the improvement.

Consideration should be given to whether to group multiple projects into a larger preservation action. For example, a twin tube tunnel with a lighting improvement in each tube could be included as one project, or could work through the process as two projects and be aligned during the prioritization process. If the construction is likely to occur as one project, grouping is certainly possible. One suggestion from CDOT was to consider the design and construction of a major construction project as two separate preservation actions, since the design portion could preceed the construction. This approach also allows the work and associated funding to be planned over multiple years. Similarly, the two fan improvement projects for the Johnson Tunnel listed in Table 2 affect the same assets; however, CDOT indicated the two improvements may be made in two separate phases depending on available funding, so it was preferred to make them separate. Care should be taken to incorporate the appropriate (life cycle) costs and ADT, reflecting all of the elements of the overall improvement project.

This issue arose during the CDOT evaluation, when a preservation action was listed for each of the Clear Creek Tunnels. Discussion ensued about combining the improvements into one project, and there was concern that the ADT is the same traffic passing through each tunnel sequentially and should therefore only be used once. However, since the total cost would have been the combined costs of each individual tunnel, the ADT would have also been combined. Ultimately, the individual projects were included in the listing.

Along the same lines is the preservation action, typically a system improvement, that affects both tubes. As indicated above, the cost of the improvement is higher because of the magnitude of the project and the impacts on traffic in both tubes, and therefore the total ADT for both tubes should be utilized for this project.

Life cycle costs should be developed for each preservation action. Costs may be ballpark estimates for use in developing CE scores, but all preservation actions must have associated costs developed prior to the AAMT meeting, and costs should reflect the work required to implement the preservation action.

3.1.2 Tunnel Information

It is very valuable to have a listing of all tunnels, and general inventory information summarizing tunnel construction, liner type, tunnel systems, and road carried as this information may be referenced during the AAMT meeting. Not all AAMT members will have familiarity with all tunnels, so this information is helpful for the evaluation and in understanding the preservation actions. In addition, Average Daily Traffic (ADT) should be collected for each tunnel and summarized in the template before arriving at the AAMT meeting.

3.2 Establishing Levels of Service (LOS)

LOS capture the performance objectives of interest and relevance to the transportation agency using measures that relate to the needs of the agency. Many transportation agencies have already developed an overall asset management strategy and have established their LOS for the entire agency. These LOS may apply as well to tunnels as to other assets in the system. CDOT indicated that they were in the process of developing their overall goals and objectives; the mission and values presented in Chapter 2 provided a good starting point for discussion with the AAMT. These discussions take considerable time, and are best to occur prior to the AAMT meeting, if possible. However, if developed in advance, the LOS should be reviewed on Day 1 with all AAMT members to understand the intent of each.

When deciding on LOS, it may be simpler to focus on the major LOS rather than have so many that it extends the evaluation time for the LOS Scoring. Our results show that the LOS that were rated quite low relative to the others (5% vs. 30% and 45%, etc.) received lower overall MOE ultimately as a result of the low LOS weight.

Several goals and objectives were identified by the CDOT AAMT team that raised questions on how to apply them in the LOS Scoring. The impact on historic resources was suggested as an LOS. The intent was to give these projects lower priority due to negative impacts, but this LOS ranked low as a decision driver relative to the other LOS, and was not included in the evaluation. Similarly, there was much discussion of the overlap between LOS. For example, improvements that extend the useful life of an asset are focused on Preservation, but many preservation projects also improve Safety, another typical LOS. Also, preservation applies to existing assets but how is it applied to projects that install a new system that doesn't currently exist. In addition, preservation may not accurately define an improvement that purely modernizes a facility or asset. Having a clear understanding of each LOS and how to apply it to the preservation actions, and doing it consistently by the group throughout the evaluation is key.

A major consideration for Colorado is the economic vitality provided as a result of their tunnels. Tourists and truckers rely on the remote tunnels for skiing and to move goods across the state. The intent of this LOS was to reward projects at these tunnels that serve trucks and resorts, but this was challenged during the workshop with the argument that every tunnel provides a certain degree of economic vitality to the state through the transportation of the working public. As an LOS that applied to virtually every improvement in every tunnel, it was not a differentiator. Therefore, the evaluation only considered improvements at the remote tunnels that would improve travel through these tunnels. It was later commented by CDOT that one approach to considering the applicability of economic vitality is to sum the points for the following: being on an interstate, ADT > 20k, truck traffic > 7%, servicing a ski resort, and having a detour > 10 miles.

3.3 The AAMT Meeting

Establishing an agenda in advance and following it is critical to completing the entire evaluation in the allotted time. The CDOT AAMT workshop took place over 1 ½ days, and addressed 37 different preservation actions in 22 tunnels. This was a significant undertaking, and discussions during the evaluations had to be curtailed in order to complete the evaluation. Two days as a minimum is probably a best case scenario to work through the process for the first time; for agencies with multiple complex tunnels and numerous preservation actions, three days may be minimal. CDOT suggested that the AAMT could even begin their review in advance of the meeting, and then compare notes when they convene. This would not facilitate as much discussion, however, and it was noted that preservation actions would need to be clearly defined for members to evaluate improvements in isolation. The second workshop with multiple agencies was a one-day event, and the group covered 14 preservation actions. This group was at a distinct disadvantage, however, since they were not all familiar with the tunnels in Colorado, nor the intent of the CDOT preservation actions.

The first part of Day 1 should include a review of the Report 816 process, so all participants understand the goals of the AAMT and generally how the metric will be utilized. Assuming that the LOS are established in advance of the meeting, the LOS should also be reviewed prior to initiating the evaluation process. Preservation actions should be presented by the champion promoting that improvement, describing the improvement and why it is needed. Preservation actions that are grouped by tunnel or by system may be discussed together, including any underlying links between projects. Participants that don't have familiarity with the tunnels and their specific needs will be heavily dependent on the description of each preservation action to gain an understanding of its need and purpose.

3.3.1 Performing the Evaluations

The prioritization can be performed in a variety of ways. The LOS Score could be calculated for each preservation action (PA), followed by the CE Score, followed by the RBU Score. Alternatively, each PA could be analyzed one by one, beginning with the LOS Score, CE Score, and RBU Score before evaluating the next PA. During the pilot project we found that a combination of these methods was most efficient, considering a group of PAs and working the entire group through the scoring before initiating another group. In this manner, PAs for one tunnel could be shepherded through the process before initiating those for another tunnel.

CHAPTER 4

Conclusions and Suggested Research

At the conclusion of the Agency Asset Management Team (AAMT) workshop with CDOT and the second workshop with multiple agencies comprising an AAMT, the research team and AAMT group were asked to reflect on the process and consider areas for improvement. Comments from the CDOT AAMT were very positive. CDOT indicated they plan to update their preservation actions and prioritization approximately every two years.

One participant commented that, in the absence of a prioritization method, the tendency is to raise the big, sexy projects to the top priority. With the Report 816 methodology, all projects are treated the same and many smaller, more cost effective projects receive higher priority. Overall, the use of the metric makes emotional decisions objective.

Another advantage of the process is that the affect of implementing the high priority improvements can be related back to safety or other LOS, by selecting the projects with an LOS Score of 4 or 5 for safety. This ability to communicate the impact of a certain capital expense within the CDOT organization and to the public is a great advantage of the system.

4.1 Areas for Future Research

4.1.1 Cost Effectiveness Score

Life cycle costs are typically a factor that an owner considers when prioritizing improvements; accordingly,cost effectiveness was built into the Report 816 metric and is treated as one of the three scores contributing to the ultimate priority of proposed improvements. However, even utilizing cost factors to achieve a greater distribution of CE scores between 0 and 100, our findings show that the majority of the improvements are either very low or very high. For low CE scores, coupled with a low relative weight compared to that of the LOS Score and RBU Score, the resulting MOE is not very dependent on CE Score. Even for the relatively few CE Scores that are 100 or close to 100, the low weight applied to CE Scores, when combining for the MOE, typically renders CE Score ineffectual. Further research could evaluate whether the equation for CE Score is appropriate, or another method to value cost effectiveness needs to be developed.

Since the CE Scores vary so much and hover around 0 and 100, a possible way to address the problem and achieve better distribution of scoring is to consider grouping low, medium and high cost improvements and analyzing them separately, then using the resulting ranking somehow to evaluate the entire population together. This is another area that could be investigated with further research on this topic.

4.1.2 Risk Based Urgency Score

The Risk Based Urgency Score (RBU) is a subjective score, as opposed to the Level of Service Score (LOS) and Cost Effectiveness Score (CE) which each follow a procedure and utilize simple equations to calculate the scores. It was noted during Workshop #2 that if the RBU Score is ultimately given a higher

relative weight than LOS and CE, it can easily be manipulated to drive the resulting priority. For this reason it was suggested that consideration be given to using equal weights for the three scores when combining for the Overall Measure of Effectiveness.

The intent of the RBU is to consider the likelihood and consequences of not making the proposed improvement. The scoring methodology considers remaining life, condition, regulatory, and risk of unplanned event. It would be most beneficial to review the table below when considering these variables to establish the RBU Score, to consider both likelihood and consequences.

Table 16. Risk Evaluation Considering Likelihood and Consequences

	Consequences				
Likelihood	Insignificant	Minor	Significant	Major	Catastrophic
Very Rare	Low	Low	Low	Moderate	High
Rare	Low	Low	Moderate	High	High
Seldom	Low	Moderate	Moderate	High	Extreme
Common	Moderate	Moderate	High	Extreme	Extreme
Frequent	Moderate	High	High	Extreme	Extreme

The agencies that participated in the second workshop suggested that a database of typical service lives for tunnel system assets would be beneficial and would help in establishing the RBU.

4.1.3 Funding and Staffing

During the workshop with multiple agencies, there was discussion regarding the planning process for various agencies and some of the issues that arise in this planning process. It was noted that uncertainty in contractor prices has an impact on which projects will fit within a given funding year, since construction prices vary from year to year depending on economic factors. One participant suggested adding project duration into the matrix for each preservation action, since many projects take more than one year to construct. A more accurate planning process occurs when funding and staffing are planned and spread across multiple years.

APPENDIX A

Evaluation Results – Pilot #1

The full results from the Report 816 process for pilot with CDOT are provided below.

Table A.1 LOS Scores

LEVEL OF SERVICE SCORE								
	Level of Service	Preservation	Mobility/ Quality of Service	Safety	Economic Vitality	Security	Environment	Score
	Weight	30	25	20	15	5	5	100
Preservation Action	**Tunnel**							
Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	4	0	4	0	0	4	**44.0**
Roof Replacement Project	EJMT	5	0	3	0	0	0	**42.0**
Fan Repair - Mechanical (Drives, Bearings, etc.)	Johnson Tunnel	3	0	3	0	0	0	**30.0**
Tunnel Ops	Beavertail	5	2	3	0	4	0	**56.0**
Shotcrete/Concrete Liner Repair	Clear Creek	4	4	5	4	0	0	**76.0**
VMS Repair/Replace due to Impact	Johnson Tunnel	5	5	5	1	0	0	**78.0**
Emergency Generator Repair	Johnson Tunnel	4	1	5	2	5	0	**60.0**
Repair Plenum Drainage and Pumping Syst.	EJMT	5	0	0	0	0	5	**35.0**
Replace Wastewater Treatment Plant	EJMT	5	0	4	0	0	5	**51.0**
LED Lighting Replacement	EJMT	5	4	4	2	1	3	**76.0**
Tunnel Operations Center	EJMT	5	5	5	5	5	0	**95.0**
Tunnel Lighting Repair	No Name	5	5	5	1	2	1	**81.0**
Replace Heat Trace with New System	EJMT	4	2	3	2	0	0	**52.0**
Liner Water Infiltration Repair	Eisenhower Tunnel	5	2	3	1	0	0	**55.0**
Replace Wall Panel Grout Beds	Eisenhower Tunnel	5	1	3	2	0	0	**53.0**
EJMT Ceiling Repairs	EJMT	5	0	5	1	0	0	**53.0**
Berm Culvert	EJMT	4	0	1	0	0	2	**30.0**
Emerg. Generator Replace Full KW	EJMT	5	1	4	4	1	0	**64.0**

Table A.1 LOS Scores (Continued)

LEVEL OF SERVICE SCORE								
	Level of Service	Preservation	Mobility/ Quality of Service	Safety	Economic Vitality	Security	Environment	Score
	Weight	30	25	20	15	5	5	100
Preservation Action	Tunnel							
Repair/Replace Lane Use Signals	EJMT	5	4	5	1	0	0	**73.0**
VMS Replacement	Wolf Creek	5	4	4	4	0	0	**78.0**
Investigate water infiltration and coating failure	Wolf Creek	4	2	1	0	0	2	**40.0**
Lighting Repair/Replacement	Reverse Curve	5	3	5	0	2	2	**69.0**
Emergency Generator Replacement	HLT	3	0	5	0	1	0	**39.0**
Liner Repair	HLT	3	2	1	0	0	0	**32.0**
Pavement Resurface	HLT	5	5	3	1	0	0	**70.0**
Crack Seal Pavement	No Name	4	1	0	0	0	0	**29.0**
LPS Light Replacement	HLT	5	3	5	0	2	2	**69.0**
Structural Liner	EJMT	5	2	2	0	0	0	**48.0**
EJMT Waterproofing	EJMT	5	3	3	1	0	0	**60.0**
Egress Signage	EJMT	3	3	5	0	0	0	**53.0**
Clear Creek Canyon Standpipes	Clear Creek	0	1	5	3	0	0	**34.0**
Callbox or cameras/Fire Extinguisher Boxes	Clear Creek	2	3	5	0	4	0	**51.0**
Traffic Barrier	EJMT	0	2	5	0	0	0	**30.0**
DTR Radio Repeaters	EJMT	0	2	5	2	5	0	**41.0**
Clear Creek Tunnel Lighting System	Clear Creek	5	5	5	4	0	1	**88.0**
Shotcrete Liner Repair/Drainage	Boulder Canyon	4	4	5	3	0	0	**73.0**

Table A.2 CE Scores

COST EFFECTIVENESS SCORE										
Preservation Action	**Tunnel**	**Capital Cost**	**Agency Oversight Cost**	**Annual Change in Costs**	**PV of LCC**	**Rem'g Life due to Preserv. Action**	**ADT (x 1000)**	**Annualized Life Cycle Cost**	**Annual Cost per Daily Vehicle**	**Score**
Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	$ 4,500,000	$ 1,350,000	$ (120,000)	$ 3,076,227	40	15	$133,085	$ 9.18	**4.4**
Roof Replacement Project	EJMT	$ 5,000,000	$ 1,500,000		$ 6,500,000	30	29	$331,625	$ 11.44	**3.5**
Fan Repair - Mechanical (Drives, Bearings, etc.	Johnson Tunnel	$ 160,000	$ 48,000		$ 208,000	50	15	$8,084	$ 0.56	**71.7**
Tunnel Ops	Beavertail	$ 100,000	$ 30,000		$ 130,000	10	16	$15,240	$ 0.95	**42.0**
Shotcrete/Concrete Liner Repair	Clear Creek	$ 17,183,500	$ 5,155,050		$ 22,338,550	50	29	$868,199	$ 29.94	**1.3**
VMS Repair/Replace due to Impact	Johnson Tunnel	$ 1,045,000	$ 313,500		$ 1,358,500	20	15	$91,313	$ 6.30	**6.4**
Emergency Generator Repair	Johnson Tunnel	$ 400,000	$ 120,000		$ 520,000	10	29	$60,960	$ 2.10	**19.0**
Repair Plenum Drainage and Pumping Syst.	EJMT	$ 2,300,000	$ 690,000	$ (50,000)	$ 2,246,126	20	29	$150,975	$ 5.21	**7.7**
Replace Wastewater Treatment Plant	EJMT	$ 4,500,000	$ 1,350,000		$ 5,850,000	40	29	$253,085	$ 8.73	**4.6**
LED Lighting Replacement	EJMT	$ 15,000,000	$ 4,500,000	$ (140,000)	$ 17,417,154	20	29	$1,170,706	$ 40.37	**1.0**
Tunnel Operations Center	EJMT	$ 10,000,000	$ 3,000,000		$ 13,000,000	10	29	$1,523,997	$ 52.55	**0.8**
Tunnel Lighting Repair	No Name	$ 200,000	$ 60,000		$ 260,000	20	15	$17,476	$ 1.17	**34.3**
Replace Heat Trace with New System	EJMT	$ 250,000	$ 75,000	$ (10,000)	$ 176,225	20	29	$11,845	$ 0.41	**97.9**
Liner Water Infiltration Repair	Eisenhower Tunnel	$ 500,000	$ 150,000		$ 650,000	50	15	$25,263	$ 1.74	**23.0**
Replace Wall Panel Grout Beds	Eisenhower Tunnel	$ 50,000	$ 15,000		$ 65,000	20	15	$4,369	$ 0.30	**100.0**
EJMT Ceiling Repairs	EJMT	$ 258,000	$ 77,400		$ 335,400	40	29	$14,510	$ 0.50	**79.9**
Berm Culvert	EJMT	$ 500,000	$ 150,000		$ 650,000	50	29	$25,263	$ 0.87	**45.9**
Emerg. Generator Replace Full KW	EJMT	$ 7,000,000	$ 2,100,000		$ 9,100,000	40	29	$393,688	$ 13.58	**2.9**
Replace Fire Extinguisher Cabinets	EJMT	$ 100,000	$ 30,000		$ 130,000	20	29	$8,738	$ 0.30	**100.0**

Table A.2 CE Scores (Continued)

COST EFFECTIVENESS SCORE										
Preservation Action	**Tunnel**	**Capital Cost**	**Agency Oversight Cost**	**Annual Change in Costs**	**PV of LCC**	**Rem'g Life due to Preserv. Action**	**ADT (x 1000)**	**Annualized Life Cycle Cost**	**Annual Cost per Daily Vehicle**	**Score**
Repair/Replace Lane Use Signals	EJMT	$ 2,880,000	$ 864,000		$ 3,744,000	20	29	$251,656	$ 8.68	**4.6**
VMS Replacement	Wolf Creek	$ 380,000	$ 114,000		$ 494,000	20	3	$33,205	$ 10.38	**3.9**
Investigate water infiltration and coating failure	Wolf Creek	$ 250,000	$ 75,000		$ 325,000	20	3	$21,845	$ 7.28	**5.5**
Lighting Repair/Replacement	Reverse Curve	$ 233,333	$ 70,000	$ (15,000)	$ 80,171	20	7	$5,389	$ 0.77	**52.0**
Emergency Generator Replacement	HLT	$ 3,500,000	$ 1,050,000	$ (20,000)	$ 4,087,705	40	14	$176,844	$ 12.63	**3.2**
Liner Repair	HLT	$ 7,640,500	$ 2,292,150		$ 9,932,650	100	14	$314,335	$ 22.45	**1.8**
Pavement Resurface	HLT	$ 1,000,000	$ 300,000	$ (75,000)	$ 404,655	15	14	$33,897	$ 2.42	**16.5**
Crack Seal Pavement	No Name	$ 100,000	$ 30,000		$ 130,000	4	14	$34,974	$ 2.50	**16.0**
LPS Light Replacement	HLT	$ 466,667	$ 140,000	$ (35,000)	$ 85,955	20	14	$5,778	$ 0.41	**96.9**
Structural Liner	EJMT	$ 20,925,000	$ 6,277,500		$ 27,202,500	50	29	$1,057,239	$ 36.46	**1.1**
EJMT Waterproofing	EJMT	$ 1,250,000	$ 375,000		$ 1,625,000	40	29	$70,301	$ 2.42	**16.5**
Egress Signage	EJMT	$ 50,000	$ 15,000		$ 65,000	25	29	$3,733	$ 0.13	**100.0**
Clear Creek Canyon Standpipes	Clear Creek	$ 1,500,000	$ 450,000		$ 1,950,000	50	11	$75,788	$ 6.89	**5.8**
Callbox or cameras/Fire Extinguisher Boxes	Clear Creek	$ 150,000	$ 45,000		$ 195,000	20	11	$13,107	$ 1.19	**33.6**
Traffic Barrier	EJMT	$ 500,000	$ 150,000		$ 650,000	25	29	$37,328	$ 1.29	**31.1**
DTR Radio Repeaters	EJMT	$ 300,000	$ 90,000		$ 390,000	10	29	$45,720	$ 1.58	**25.4**
Clear Creek Tunnel Lighting System	Clear Creek	$ 6,500,000	$ 1,950,000		$ 8,450,000	20	11	$567,973	$ 51.63	**0.8**
Shotcrete Liner Repair/Drainage	Boulder Canyon	$ 2,500,000	$ 750,000	$ (5,000)	$ 3,121,351	50	4	$121,313	$ 30.33	**1.3**

Table A.3 RBU Scores

RISK-BASED URGENCY SCORE									
Preservation Action	Tunnel	Remaining Life	Asset's Theoretical Service Life	% Life Expended	Condition (1=Good, 4=Severe)	Regulatory Compliance Issue? (Y/N)	Risk of Unplanned Event (1=Low, 3=High)	Risk-Based Urgency (1 to 10)	Risk-Based Urgency Score
Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	12	50	76.0	3	Y	3	8	**80.0**
Roof Replacement Project	EJMT	0	30	100.0	4	N	2	8	**80.0**
Fan Repair - Mechanical (Drives, Bearings, etc.)	Johnson Tunnel	12	50	76.0	3	N	1	3	**30.0**
Tunnel Ops	Beavertail	0	10	100.0	4	Y	3	9	**90.0**
Shotcrete/Concrete Liner Repair	Clear Creek	19	85	77.6	4	N	3	8	**80.0**
VMS Repair/Replace due to Impact	Johnson Tunnel	0	20	100.0	4	Y	3	9	**90.0**
Emergency Generator Repair	Johnson Tunnel	2	40	95.0	4	Y	2	9	**90.0**
Repair Plenum Drainage and Pumping Syst.	EJMT	3	40	92.5	4	N	3	10	**100.0**
Replace Wastewater Treatment Plant	EJMT	0	40	100.0	4	Y	2	7	**70.0**
LED Lighting Replacement	EJMT	4	20	80.0	2	Y	2	8	**80.0**
Tunnel Operations Center	EJMT	0	10	100.0	2	Y	3	8	**80.0**
Tunnel Lighting Repair	No Name	18	20	N/A	2	Y	3	7	**70.0**
Replace Heat Trace with New System	EJMT	0	20	100.0	3	N	2	8	**80.0**
Liner Water Infiltration Repair	Eisenhower Tunnel	58	100	42.0	2.4	N	1	9	**90.0**
Replace Wall Panel Grout Beds	Eisenhower Tunnel	1	50	98.0	4	N	1	9	**90.0**
EJMT Ceiling Repairs	EJMT	0	85	100.0	4	N	2	9	**90.0**
Berm Culvert	EJMT	30	75	60.0	3	N	2	6	**60.0**
Emerg. Generator Replace Full KW	EJMT	2	40	N/A	3	Y	3	8	**80.0**
Replace Fire Extinguisher Cabinets	EJMT	0	30	100.0	4	Y	3	3	**30.0**

Table A.3 RBU Scores (Continued)

RISK-BASED URGENCY SCORE									
Preservation Action	**Tunnel**	**Remaining Life**	**Asset's Theoretical Service Life**	**% Life Expended**	**Condition (1=Good, 4=Severe)**	**Regulatory Compliance Issue? (Y/N)**	**Risk of Unplanned Event (1=Low, 3=High)**	**Risk-Based Urgency (1 to 10)**	**Risk-Based Urgency Score**
Repair/Replace Lane Use Signals	EJMT	4	20	80.0	4	Y	3	10	**100.0**
VMS Replacement	Wolf Creek	0	20	100.0	4	Y	3	9	**90.0**
Investigate water infiltration and coating failure	Wolf Creek	25	30	16.7	2	N	1	2	**20.0**
Lighting Repair/Replacement	Reverse Curve	1	20	95.0	1	Y	1	10	**100.0**
Emergency Generator Replacement	HLT	14	40	65.0	1	Y	3	8	**80.0**
Liner Repair	HLT	74	100	26.0	3	N	2	2	**20.0**
Pavement Resurface	HLT	1	20	95.0	3	N	1	6	**60.0**
Crack Seal Pavement	No Name	15	40	62.5	2	N	1	1	**10.0**
LPS Light Replacement	HLT	1	20	95.0	1	Y	1	10	**100.0**
Structural Liner	EJMT	30	100	70.0	3	N	1	4	**40.0**
EJMT Waterproofing	EJMT	0	25	100.0	3	N	1	8	**80.0**
Egress Signage	EJMT	1	25	96.0	3	Y	3	10	**100.0**
Clear Creek Canyon Standpipes	Clear Creek	N/A	50		N/A	Y	3	3	**30.0**
Callbox or cameras/Fire Extinguisher Boxes	Clear Creek	N/A	50		N/A	Y	3	4	**40.0**
Traffic Barrier	EJMT	N/A	25		N/A	Y	3	3	**30.0**
DTR Radio Repeaters	EJMT	N/A	10		N/A	Y	3	7	**70.0**
Clear Creek Tunnel Lighting System	Clear Creek	0	20	100.0	2	Y	3	7	**70.0**
Shotcrete Liner Repair/Drainage	Boulder Canyon	5	50	90.0	4	N	3	8	**80.0**

Table A.4 Overall Measure of Effectiveness Scores and Calculated Priority

OVERALL MEASURE OF EFFECTIVENESS						
	Weight	35	20	45	100	
Preservation Action	Tunnel	Levels of Service Score	Cost Effectiveness Score	Risk Based Urgency Score	Total Score	Calculated Priority
LPS Light Replacement	HLT	69.0	96.9	100.0	**88.5**	1
Egress Signage	EJMT	53.0	100.0	100.0	**83.6**	2
Lighting Repair/Replacement	Reverse Curve	69.0	52.0	100.0	**79.5**	4
Replace Wall Panel Grout Beds	Eisenhower Tunnel	53.0	100.0	90.0	**79.1**	5
EJMT Ceiling Repairs	EJMT	53.0	79.9	90.0	**75.0**	6
Replace Heat Trace with New System	EJMT	52.0	97.9	80.0	**73.8**	7
Repair/Replace Lane Use Signals	EJMT	73.0	4.6	100.0	**71.5**	8
Tunnel Operations Center	EJMT	95.0	0.8	80.0	**69.4**	9
VMS Repair/Replace due to Impact	Johnson Tunnel	78.0	6.4	90.0	**69.1**	10
VMS Replacement	Wolf Creek	78.0	69.9	90.0	**81.8**	3
Tunnel Ops	Beavertail	56.0	42.0	90.0	**68.5**	11
Tunnel Lighting Repair	No Name	81.0	34.3	70.0	**66.7**	12
Emergency Generator Repair	Johnson Tunnel	60.0	19.0	90.0	**65.3**	13
Liner Water Infiltration Repair	Eisenhower Tunnel	55.0	23.0	90.0	**64.3**	14
Shotcrete/Concrete Liner Repair	Clear Creek	76.0	1.3	80.0	**62.9**	15
LED Lighting Replacement	EJMT	76.0	1.0	80.0	**62.8**	16
Clear Creek Tunnel Lighting System	Clear Creek	88.0	0.8	70.0	**62.5**	17
Shotcrete Liner Repair/Drainage	Boulder Canyon	73.0	1.3	80.0	**61.8**	18
EJMT Waterproofing	EJMT	60.0	16.5	80.0	**60.3**	19
Emerg. Generator Replace Full KW	EJMT	64.0	2.9	80.0	**59.0**	20
Repair Plenum Drainage and Pumping	EJMT	35.0	7.7	100.0	**58.8**	21
Pavement Resurface	HLT	70.0	16.5	60.0	**54.8**	22
Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	44.0	4.4	80.0	**52.3**	23
Roof Replacement Project	EJMT	42.0	3.5	80.0	**51.4**	24
Replace Fire Extinguisher Cabinets	EJMT	50.0	100.0	30.0	**51.0**	25
DTR Radio Repeaters	EJMT	41.0	25.4	70.0	**50.9**	26
Emergency Generator Replacement	HLT	39.0	3.2	80.0	**50.3**	27
Replace Wastewater Treatment Plant	EJMT	51.0	4.6	70.0	**50.3**	28

Table A.4 Overall Measure of Effectiveness Scores and Calculated Priority (Continued)

OVERALL MEASURE OF EFFECTIVENESS						
	Weight	35	20	45	100	
Preservation Action	**Tunnel**	**Levels of Service Score**	**Cost Effectiveness Score**	**Risk Based Urgency Score**	**Total Score**	**Calculated Priority**
Berm Culvert	EJMT	30.0	45.9	60.0	**46.7**	29
Callbox or cameras/Fire Extinguisher	Clear Creek	51.0	33.6	40.0	**42.6**	30
Fan Repair - Mechanical (Drives, Bear	Johnson Tunnel	30.0	71.7	30.0	**38.3**	31
Structural Liner	EJMT	48.0	1.1	40.0	**35.0**	32
Traffic Barrier	EJMT	30.0	31.1	30.0	**30.2**	33
Clear Creek Canyon Standpipes	Clear Creek	34.0	5.8	30.0	**26.6**	34
Investigate water infiltration and coat	Wolf Creek	40.0	5.5	20.0	**24.1**	35
Liner Repair	HLT	32.0	1.8	20.0	**20.6**	36
Crack Seal Pavement	No Name	29.0	16.0	10.0	**17.9**	37

Table A.5 Prioritization- Calculated and User Priority

PRIORITIZATION				
Preservation Action	**Tunnel**	**Total Score**	**Calculated Priority**	**User Priority**
LPS Light Replacement	HLT	**88.5**	1	1
VMS Replacement	Wolf Creek	**81.8**	3	2
Egress Signage	EJMT	**83.6**	2	3
Replace Fire Extinguisher Cabinets	EJMT	**51.0**	25	4
Lighting Repair/Replacement	Reverse Curve	**79.5**	4	5
Replace Wall Panel Grout Beds	Eisenhower Tunnel	**79.1**	5	6
EJMT Ceiling Repairs	EJMT	**75.0**	6	7
Replace Heat Trace with New System	EJMT	**73.8**	7	8
Repair/Replace Lane Use Signals	EJMT	**71.5**	8	9
VMS Repair/Replace due to Impact	Johnson Tunnel	**69.1**	10	10
Tunnel Ops	Beavertail	**68.5**	11	11
Tunnel Lighting Repair	No Name	**66.7**	12	12
Emergency Generator Repair	Johnson Tunnel	**65.3**	13	13
Liner Water Infiltration Repair	Eisenhower Tunnel	**64.3**	14	14
LED Lighting Replacement	EJMT	**62.8**	16	15
Tunnel Operations Center	EJMT	**69.4**	9	16
Shotcrete/Concrete Liner Repair	Clear Creek	**63.1**	15	17
Clear Creek Tunnel Lighting System	Clear Creek	**62.5**	17	18
Shotcrete Liner Repair/Drainage	Boulder Canyon	**61.8**	18	19
EJMT Waterproofing	EJMT	**60.3**	19	20
Emerg. Generator Replace Full KW	EJMT	**59.0**	20	21
Repair Plenum Drainage and Pumping	EJMT	**58.8**	21	22

Table A.5 Prioritization- Calculated and User Priority (Continued)

PRIORITIZATION				
Preservation Action	**Tunnel**	**Total Score**	**Calculated Priority**	**User Priority**
Pavement Resurface	HLT	**54.8**	22	23
Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	**52.3**	23	24
DTR Radio Repeaters	EJMT	**50.9**	26	25
Roof Replacement Project	EJMT	**51.4**	24	26
Emergency Generator Replacement	HLT	**50.3**	27	27
Replace Wastewater Treatment Plant	EJMT	**50.3**	28	28
Berm Culvert	EJMT	**46.7**	29	29
Callbox or cameras/Fire Extinguisher B	Clear Creek	**42.6**	30	30
Fan Repair - Mechanical (Drives, Beari	Johnson Tunnel	**38.3**	31	31
Structural Liner	EJMT	**35.0**	32	32
Traffic Barrier	EJMT	**30.2**	33	33
Clear Creek Canyon Standpipes	Clear Creek	**26.6**	34	34
Investigate water infiltration and coati	Wolf Creek	**24.1**	35	35
Liner Repair	HLT	**20.6**	36	36
Crack Seal Pavement	No Name	**17.9**	37	37

Table A.6 Prioritization and Funding

PRIORITIZATION and FUNDING											
Preservation Action	Tunnel	Total Score	Calculated Priority	User Priority	Capital Cost	Agency Oversight	Subtotal Cost	Funding Year (1+)	Escalation	Total Cost	Cumulative Cost
LPS Light Replacement	HLT	88.5	1	1	$ 466,667	$ 140,000	$ 606,667	1	$ -	$ 606,667	$1,100,667
VMS Replacement	Wolf Creek	81.8	3	2	$ 380,000	$ 114,000	$ 494,000	1	$ -	$ 494,000	$1,100,667
Egress Signage	EJMT	83.6	2	3	$ 50,000	$ 15,000	$ 65,000	1	$ -	$ 65,000	$1,165,667
Replace Fire Extinguisher Cabinets	EJMT	51.0	25	4	$ 100,000	$ 30,000	$ 130,000	1	$ -	$ 130,000	$1,295,667
Lighting Repair/Replacement	Reverse Curve	79.5	4	5	$ 233,333	$ 70,000	$ 303,333	1	$ -	$ 303,333	$1,599,000
Replace Wall Panel Grout Beds	Eisenhower Tunnel	79.1	5	6	$ 50,000	$ 15,000	$ 65,000	1	$ -	$ 65,000	$1,664,000
EJMT Ceiling Repairs	EJMT	75.0	6	7	$ 258,000	$ 77,400	$ 335,400	1	$ -	$ 335,400	$1,999,400
Replace Heat Trace with New System	EJMT	73.8	7	8	$ 250,000	$ 75,000	$ 325,000	1	$ -	$ 325,000	$2,324,400
Repair/Replace Lane Use Signals	EJMT	71.5	8	9	$ 2,880,000	$ 864,000	$ 3,744,000	1	$ -	$ 3,744,000	$6,068,400
VMS Repair/Replace due to Impact	Johnson Tunnel	69.1	10	10	$ 1,045,000	$ 313,500	$ 1,358,500	1	$ -	$ 1,358,500	$ 7,426,900
Tunnel Ops	Beavertail	68.5	11	11	$ 100,000	$ 30,000	$ 130,000	1	$ -	$ 130,000	$7,556,900
Tunnel Lighting Repair	No Name	66.7	12	12	$ 200,000	$ 60,000	$ 260,000	1	$ -	$ 260,000	$7,816,900
Emergency Generator Repair	Johnson Tunnel	65.3	13	13	$ 400,000	$ 120,000	$ 520,000	1	$ -	$ 520,000	$8,336,900
Liner Water Infiltration Repair	Eisenhower Tunnel	64.3	14	14	$ 500,000	$ 150,000	$ 650,000	1	$ -	$ 650,000	$8,986,900
LED Lighting Replacement	EJMT	62.8	16	15	$ 15,000,000	$ 4,500,000	$ 19,500,000	2	$ 585,000	$ 20,085,000	$29,071,900
Tunnel Operations Center	EJMT	69.4	9	16	$ 10,000,000	$ 3,000,000	$ 13,000,000	3	$ 791,700	$ 13,791,700	$42,863,600
Shotcrete/Concrete Liner Repair	Clear Creek	63.1	15	17	$ 17,183,500	$ 5,155,050	$ 22,338,550	4	$ 2,071,387	$ 24,409,937	$67,273,537
Clear Creek Tunnel Lighting System	Clear Creek	62.5	17	18	$ 6,500,000	$ 1,950,000	$ 8,450,000	5	$ 1,060,549	$ 9,510,549	$76,784,086
Shotcrete Liner Repair/Drainage	Boulder Canyon	61.8	18	19	$ 2,500,000	$ 750,000	$ 3,250,000	5	$ 407,904	$ 3,657,904	$80,441,990
EJMT Waterproofing	EJMT	60.3	19	20	$ 1,250,000	$ 375,000	$ 1,625,000	5	$ 203,952	$ 1,828,952	$82,270,942
Emerg. Generator Replace Full KW	EJMT	59.0	20	21	$ 7,000,000	$ 2,100,000	$ 9,100,000	5	$ 1,142,130	$ 10,242,130	$92,513,072
Repair Plenum Drainage and Pumping	EJMT	58.8	21	22	$ 2,300,000	$ 690,000	$ 2,990,000	5	$ 375,271	$ 3,365,271	$95,878,343

Table A.6 Prioritization and Funding (Continued)

PRIORITIZATION and FUNDING											
Preservation Action	**Tunnel**	**Total Score**	**Calculated Priority**	**User Priority**	**Capital Cost**	**Agency Oversight**	**Subtotal Cost**	**Funding Year (1+)**	**Escalation**	**Total Cost**	**Cumulative Cost**
Pavement Resurface	HLT	**54.8**	22	23	$ 1,000,000	$ 300,000	$ 1,300,000	6	$ 207,056	$ 1,507,056	$97,385,399
Fan Motor Modification/Replacement - Elec.	Johnson Tunnel	**52.3**	23	24	$ 4,500,000	$ 1,350,000	$ 5,850,000	6	$ 931,753	$ 6,781,753	$104,167,153
DTR Radio Repeaters	EJMT	**50.9**	26	25	$ 300,000	$ 90,000	$ 390,000	6	$ 62,117	$ 452,117	$104,619,270
Roof Replacement Project	EJMT	**51.4**	24	26	$ 5,000,000	$ 1,500,000	$ 6,500,000	6	$ 1,035,281	$ 7,535,281	$112,154,551
Emergency Generator Replacement	HLT	**50.3**	27	27	$ 3,500,000	$ 1,050,000	$ 4,550,000	6	$ 724,697	$ 5,274,697	$117,429,248
Replace Wastewater Treatment Plant	EJMT	**50.3**	28	28	$ 4,500,000	$ 1,350,000	$ 5,850,000	6	$ 931,753	$ 6,781,753	$124,211,002
Berm Culvert	EJMT	**46.7**	29	29	$ 500,000	$ 150,000	$ 650,000	6	$ 103,528	$ 753,528	$124,964,530
Callbox or cameras/Fire Extinguisher	Clear Creek	**42.6**	30	30	$ 150,000	$ 45,000	$ 195,000	6	$ 31,058	$ 226,058	$125,190,588
Fan Repair - Mechanical (Drives, Bear	Johnson Tunnel	**38.3**	31	31	$ 160,000	$ 48,000	$ 208,000	6	$ 33,129	$ 241,129	$125,431,717
Structural Liner	EJMT	**35.0**	32	32	$ 20,925,000	$ 6,277,500	$ 27,202,500	7	$ 5,278,708	$ 32,481,208	$157,912,925
Traffic Barrier	EJMT	**30.2**	33	33	$ 500,000	$ 150,000	$ 650,000	7	$ 126,134	$ 776,134	$158,689,059
Clear Creek Canyon Standpipes	Clear Creek	**26.6**	34	34	$ 1,500,000	$ 450,000	$ 1,950,000	8	$ 448,254	$ 2,398,254	$161,087,313
Investigate water infiltration and coa	Wolf Creek	**24.1**	35	35	$ 250,000	$ 75,000	$ 325,000	8	$ 74,709	$ 399,709	$161,487,022
Liner Repair	HLT	**20.6**	36	36	$ 7,640,500	$ 2,292,150	$ 9,932,650	8	$ 2,283,257	$ 12,215,907	$173,702,928
Crack Seal Pavement	No Name	**17.9**	37	37	$ 100,000	$ 30,000	$ 130,000	8	$ 29,884	$ 159,884	$173,862,812