



# Colorado Department of Transportation SHRP2 NDT for Concrete Tunnel Linings Update (R06G)

Colorado DOT Tunnel Showcase Event

Golden, CO  
August 8th, 2017



U.S. Department of Transportation  
Federal Highway Administration

AMERICAN ASSOCIATION  
OF STATE HIGHWAY AND  
TRANSPORTATION OFFICIALS

AASHTO



# Tunnel Inspection/ Asset Management & LiDAR/ IRT Scanning Evaluation Program

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# CDOT Statement of Support



# CDOT Tunnel Overview

- # of Vehicular Tunnels: 39 total
  - On-System 20 vehicular, 2 closed
  - Off- System 11 with 6 closed
- Types of Tunnels:
  - Rock Lined
  - Cast in Place Lined
  - Shotcrete Lined
- Max Elevation: 11,158 ft with avg snowfall of 380 inches
- Current Asset Value Estimate - \$1.8 Billion



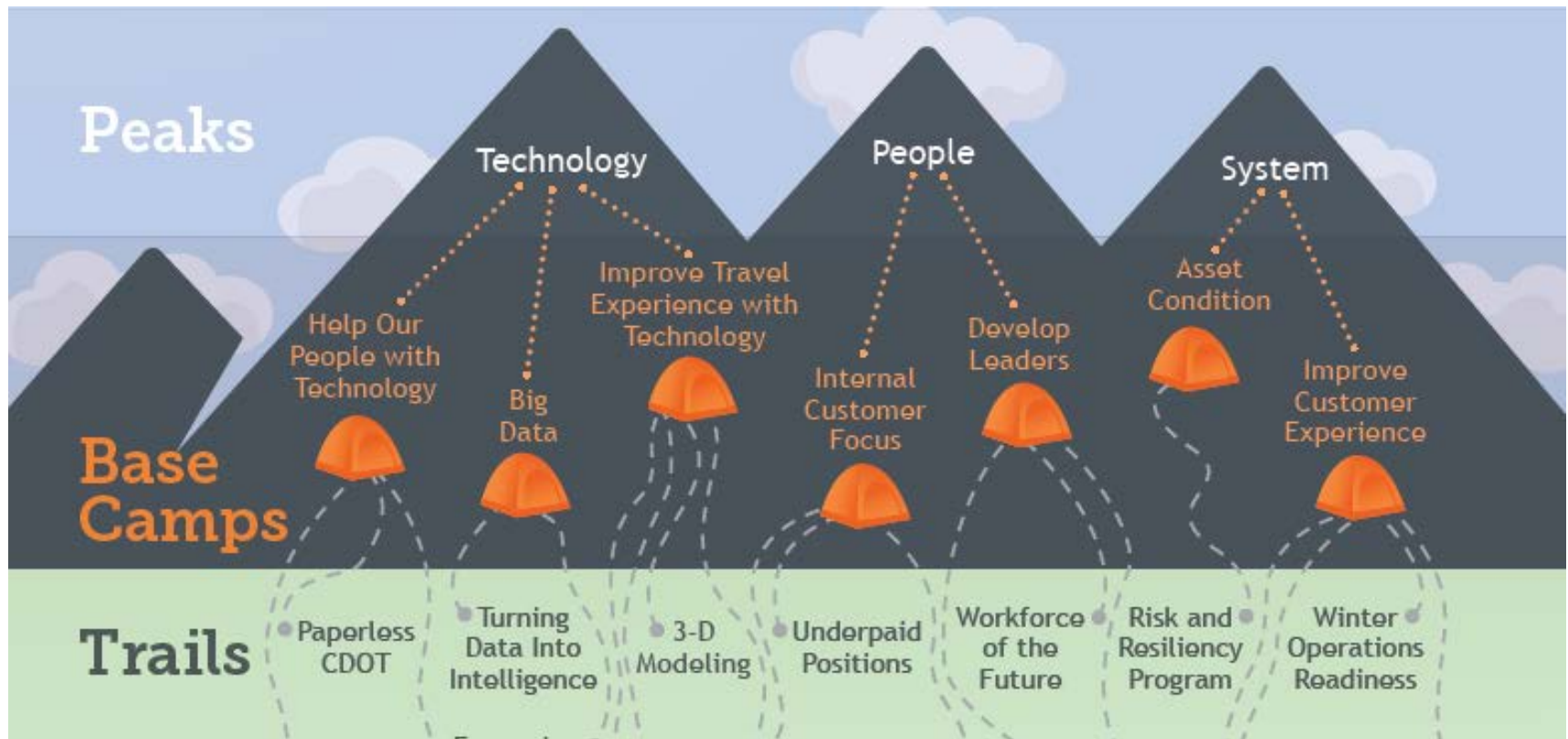
# Why Colorado?



- Number of tunnels
- Environment
- Past Research
- Olson Engineering
- FHWA

# Supports the Peaks

- Supports CDOT Goals



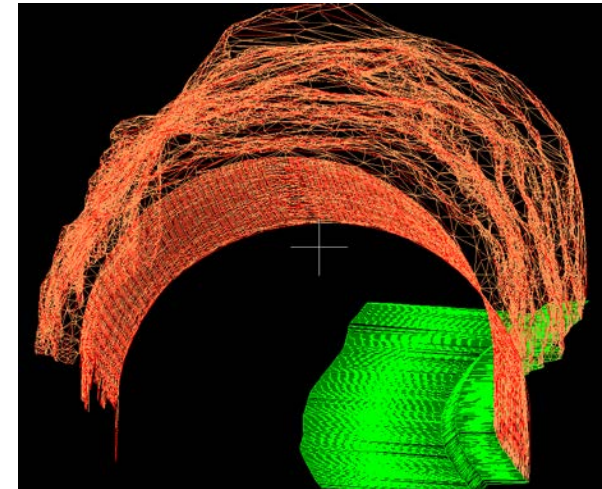
# SHRP2 Plan of Action

- Begin 2015
  - Figure out program
  - Implementation support meeting
  - Analyze different options



- 2016

- Implementation of NDT technique



- 2017

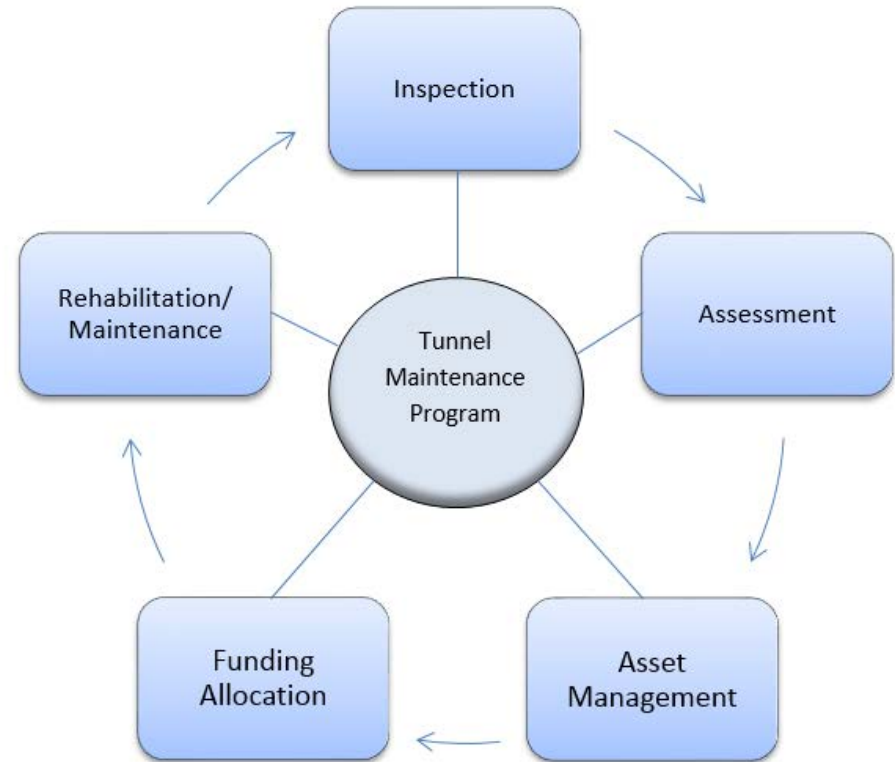
- Expanded Efforts
- Showcase
- Report

# SHRP2 Plan of Action

## Proof of Concept

### Use in:

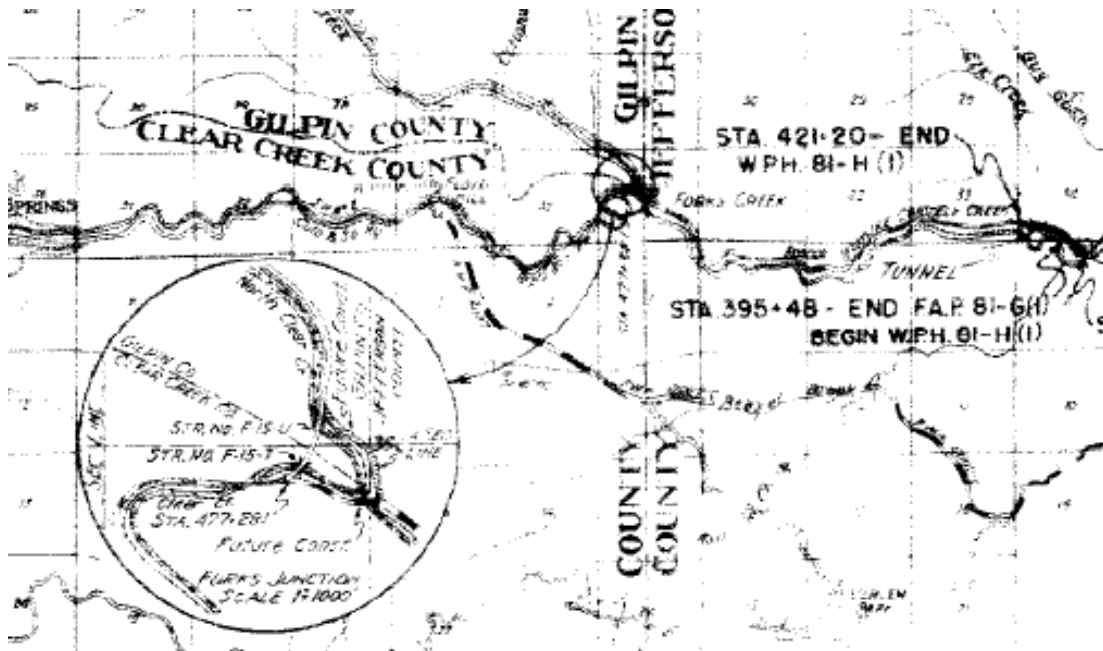
- Inspection
  - Asset Management
  - Design
  - Construction
- and integrate into cycle





# SHRP2 Plan of Action 2016

- Built in 1940's
- Abandoned Tunnel 1990's
- Shotcrete and CIP Lined Sections



# SHRP2 Plan of Action 2017

- Expand mobile scanning to Interstate tunnels
- Collect and analyze temperature in longer tunnel to optimize collection timing
- Tile lined Hanging Lake Tunnel
- Data collection in Clear Creek tunnels 1,2,3,5 & 6



# Implementation

- Selected Method
  - Mobile LiDAR with Thermal Camera
  - Technology
- Service Provider:
  - Surveying and Mapping, Inc. (SAM)



# Surveying and Mapping, Inc.

- How did we get to SAM?
  1. Application with inspection program
  2. Mobile
  3. Cost Effective
  4. Capabilities of Contractor



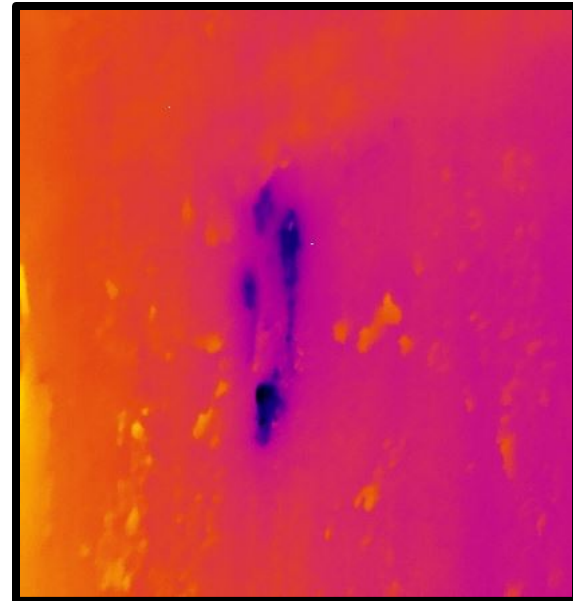
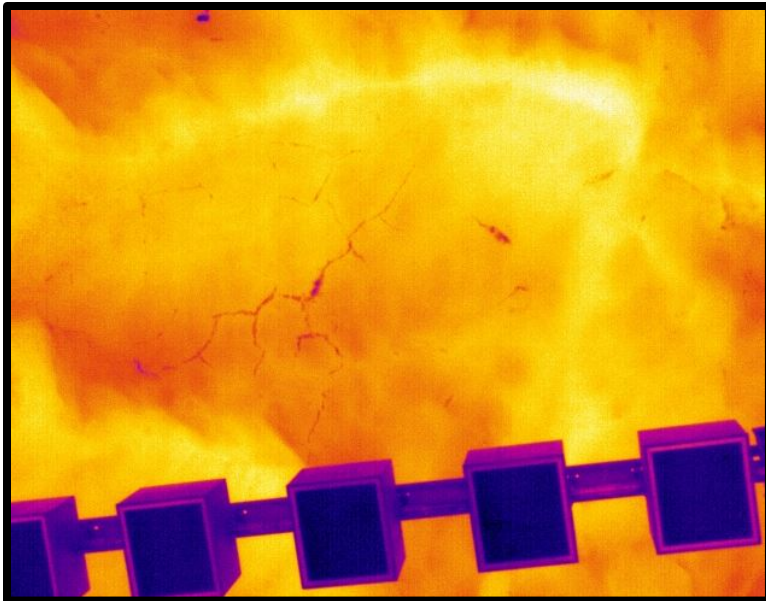
# The Grass Roots

- CDOT attended a brownbag at a private firm
  - Brownbag topic was LiDAR, highlighting mobile acquisition and DOT experience
  - CDOT approached SAM with interest
  - Follow up meeting was set
  - CDOT pitched the concept (challenge)
  - SAM accepted and started investigating



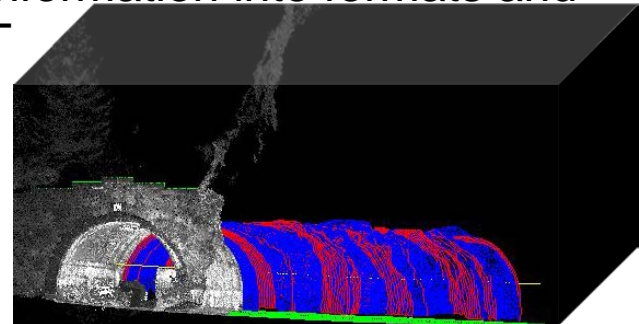
# First Steps

- Moving to the “The Laboratory” (Tunnel 4)
  - 1) Tunnel 4 is an abandoned highway tunnel
  - 2) Worked with Flir’s Scientific Division
  - 3) Tested multiple cameras and lenses



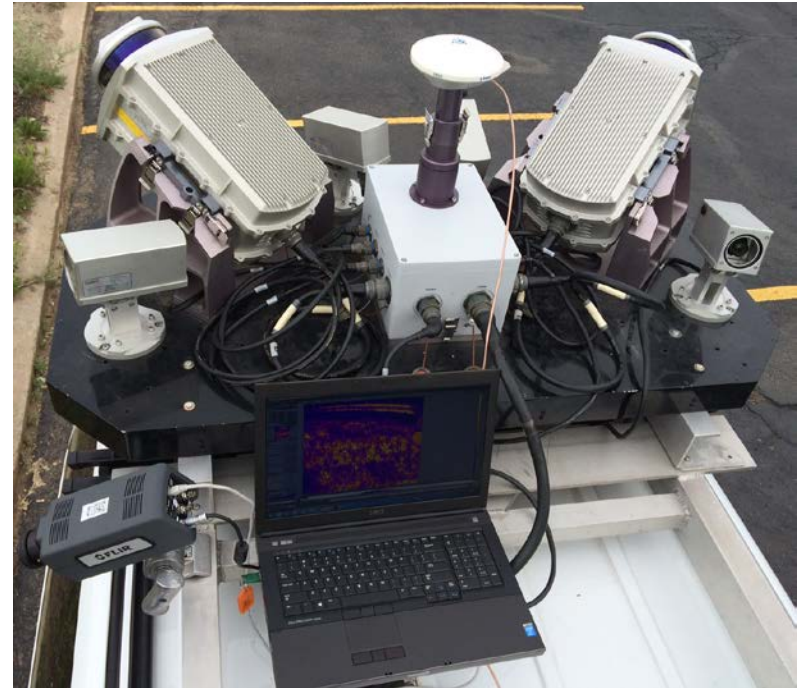
# Contracting

- Funding
  - SAM, LLC. had multiple existing NPS contracts with CDOT
- Scoping
  - Approached as a Research and Development Project
  - Defined CDOT's Goals within and around SHPR2 strategic goals
  - Broke out Deliverables into 2 groups
    - Existing
      - » SAM's standard DOT compliant formats
    - Goals
      - » Incorporating the thermal information into formats and usable platforms for a DOT



# The Foundation

- Mobile LiDAR
  - Survey Grade Accuracy
  - Up to 500,000 pts per second
  - Military grade IMU
- Thermal Camera
  - Flir A6700sc series
  - Cooled camera
  - High frame rate
  - Fast integration time
  - Exports suitable for integration with our mobile system

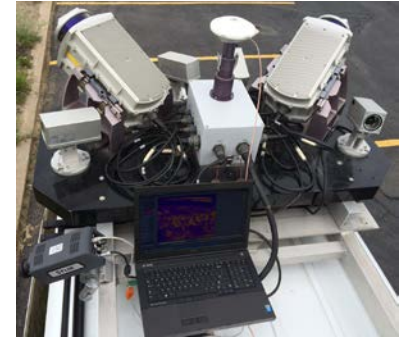




# The Foundation

- **Temperature Study**

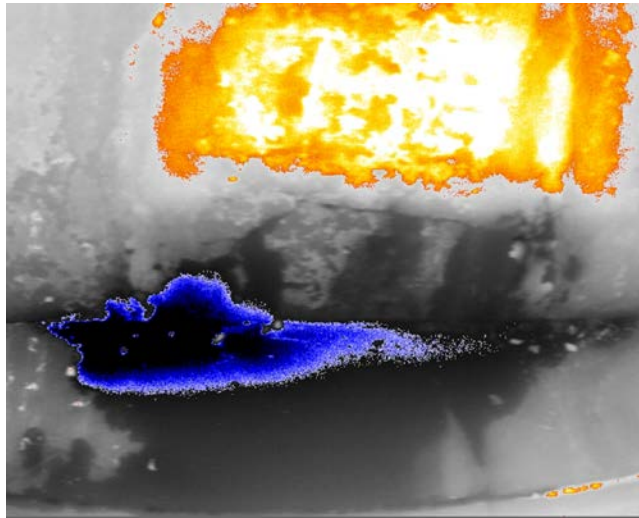
- Thermocouples installed in long tunnel 4000LF.
- Compare temperatures of known delamination and solid areas to determine ideal conditions for collection
- Run Ventilation or Not?



# Validation

Finding areas of interest and comparing to confirm effectiveness.

Thermal Image



Actual Photo



# Lessons

- Entry level thermal cameras will not meet expectations
- Renting or owning cameras
- # of cameras and processing
- Artificial warming at portals from sun during daytime collection
- Hard permanent reference markers installed for future monitoring



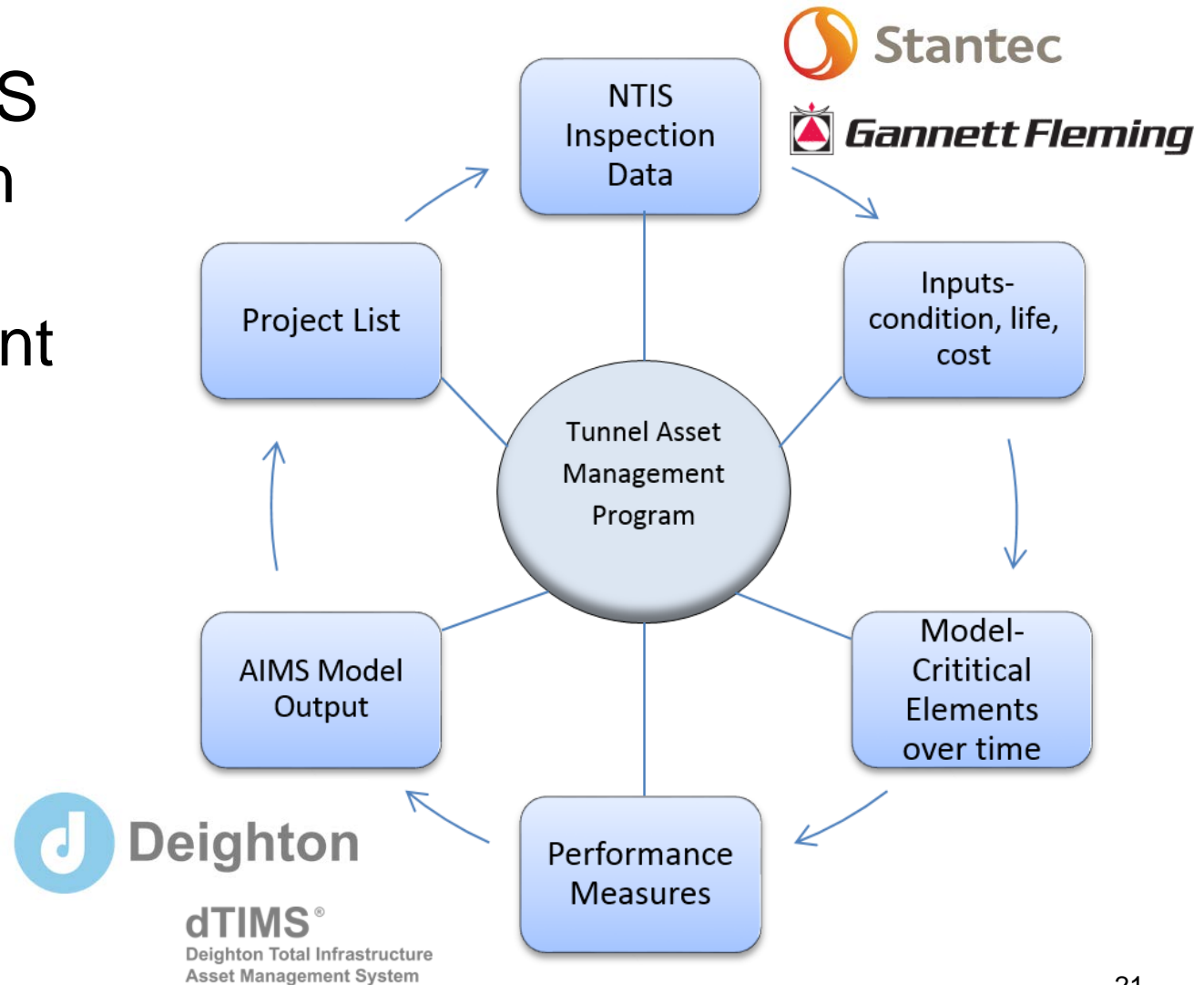
# Lessons

- Camera calibration
- Time of day for best thermal gradients
- Snap shot or long term observations
- Deliverables
  - Lidar
  - 3D model
  - Data for inspectors and design



# Tunnel Asset Management

- Tunnel NTIS Data Driven Asset Management Cycle



# Tunnel Asset Management

- Tunnel Data – Update with NTIS
  - Initially using past inspection data.

Clear Creek #1		F-15-AY		Length: 883 ft						
Structural			Condition				Life			
Element			Criticality	Eq Pct	WCI	Adj Score	Year Instl	Age	Exp Life	Eq Pct
Liner			5.00	71%	2.17	1.552				
Element	Total Quantity	CS1	CS2	CS3	CS4					
10001	Cast-in-Place Concrete Tunnel Liner	18422	0	18422	0	0	1951	64	75	14.67%
10003	Shotcrete Tunnel Liner	32730	0	23893	8837	0	1951	64	50	-28.00%
10006	Unlined Rock Tunnel	0								
Ceiling Panels			0.00	0%	0.00	0.000				
Element	Total Quantity	CS1	CS2	CS3	CS4					
10090	Steel Ceiling Panels	0								
10091	Concrete Ceiling Panels	0								
Hangers and Anchorages			0.00	0%	0.00	0.000				
Element	Total Quantity	CS1	CS2	CS3	CS4					
10080	Steel Hangers and Anchorages	0								
Wall Panels			0.00	0%	0.00	0.000				
Element	Total Quantity	CS1	CS2	CS3	CS4					
10042	Tile Lined Concrete Panels	0								
Portal			2.00	29%	2.00	0.571				
Element	Total Quantity	CS1	CS2	CS3	CS4					
10051	Concrete Portal	0								
10055	Masonry Portal	1775	0	1775	0	0	1951	64	100	36.00%
10059	Other Portal	0								
						WCI	2.123		Life (Min) -28.00%	
						WCI (%)	63%		Life (%) -28.00%	

# Tunnel Asset Management

- Age/Life Transition per Condition State

				<i>Final</i>					
				Median Years				Age	Expected Life
				CS1-CS2	CS2-CS3	CS3-CS4	CS4		
<b>Structural Elements</b>	Liner	10001	<i>Cast-in-Place Concrete Tunnel Liner</i>	30	15	15	0		75
		10003	<i>Shotcrete Tunnel Liner</i>	15	15	10	0		50
		10006	<i>Unlined Rock Tunnel</i>	35	25	20	0		100
	Ceiling	10090	<i>Steel Ceiling Panels</i>	50	30	15	0		100
		10091	<i>Concrete Ceiling Panels</i>	35	25	10	0		75
	Steel Hangers and Anchor	10080	<i>Steel Hangers and Anchorages</i>	35	25	20	0		85
	Wall Panels	10042	<i>Tile Lined Concrete Panels</i>	35	25	10	0		75
	Portals	10051	<i>Concrete Portal</i>	20	25	15	0		75
		10055	<i>Masonry Portal</i>	30	45	15	0		100
		10059	<i>Other Portal</i>	35	25	20	0		100

Figure 4: Median Years Sample

# Tunnel Asset Management

- Treatment Types Minor, Major, Replace
- Unit Costs – Important!

CDOT Tunnels Maintenance/Benefit Worksheet

Element	Type	Unit Cost	Unit	Trigger(s) of Available Funding Options	
10001, 10003, 10006	Liner	Minor	\$ 250.00	SF	Liner WCI $\geq 2.2$ and $< 2.5$
10001, 10003, 10006	Liner	Major	\$ 500.00	SF	Liner WCI $\geq 2.5$ or %CS4 $\geq 0\%$
10001, 10003, 10006	Liner	Replace	\$ 670.00	SF	Life $< 0\%$ and WCI $\geq 2.5$ or %CS4 $>30\%$
10090, 10091	Ceiling Panels	Minor	\$ 370.00	SF	Ceiling Panels WCI $\geq 2.2$ and $< 2.5$
10090, 10091	Ceiling Panels	Major	\$ 300.00	SF	Ceiling Panels WCI $\geq 2.5$ or %CS4 $>0\%$
10090, 10091	Ceiling Panels	Replace	\$ 200.00	SF	Life $< 0\%$ and WCI $\geq 2.5$ or %CS4 $>30\%$
10080	Steel Hangers and Anchorages	Minor	\$ 150.00	EA	H&A WCI $\geq 2.2$ and $< 2.5$
10080	Steel Hangers and Anchorages	Major	\$ 300.00	EA	H&A WCI $\geq 2.5$ or %CS4 $>0\%$
10080	Steel Hangers and Anchorages	Replace	\$ 1,300.00	EA	Life $< 0\%$ and WCI $\geq 2.5$ or %CS4 $>25\%$
10042	Tile Lined Concrete Panels	Minor	\$ 15.00	SF	Wall Panels WCI $\geq 2.2$ and $< 2.5$
10042	Tile Lined Concrete Panels	Major	\$ 80.00	SF	Wall Panels WCI $\geq 2.5$
10042	Tile Lined Concrete Panels	Replace	\$ 65.00	SF	Life $< 0\%$ and WCI $\geq 2.5$ or %CS4 $>40\%$



# Tunnel Asset Management

- Identify Critical Elements
- Tunnel NTIS Element #

The following tables describe the key elements of each component and the weight of the element in the overall component score.

Structural		
Element	NTIS/*CTIIM Number(s)	Criticality
<b>Liner</b>	10001, 10003, 10006	5
<b>Ceiling Panels</b>	10090, 10091	5
<b>Steel Hangers and Anchorages</b>	10080	5
<b>Tile Lined Concrete Panels</b>	10042	3
<b>Portals</b>	10051, 10055, 10059	2

Table 1: Structural Criticality

Mechanical Systems		
Element	NTIS/*CTIIM Number	Criticality
<b>Ventilation System</b>	10200	5
<b>Fan Motors</b>	*10202	3
<b>Emergency Generator System</b>	10400	3
<b>Drainage and Pumping System</b>	10300	3
<b>Water Treatment System</b>	*10310	2

Table 2: Mechanical System Criticality

Fire/Life Safety/Security Systems		
Element	NTIS/*CTIIM Number	Criticality
<b>Fire Detection System</b>	10650	5
Fire Detection System	10700	5
<b>Water Line for Fire Protection</b>	*10701	5
<b>Tunnel Operations and Security</b>	10800	5

Table 3: Fire Life Safety Criticality

Electrical Systems		
Element	NTIS/*CTIIM Number	Criticality
<b>Electrical Distribution System</b>	10500	5
Incoming Power Regulators	*10502	5
Transformers	*10503	5
Switchgear	*10504	5
<b>Motor Control Centers</b>	*10505	5

Table 4: Electrical Criticality

Lighting Systems		
Element	NTIS/*CTIIM Number	Criticality
<b>Tunnel Lighting System</b>	10600	5

Table 5: Lighting Criticality

Civil Elements		
Element	NTIS/*CTIIM Number	Criticality
<b>Traffic Barrier</b>	10161	5

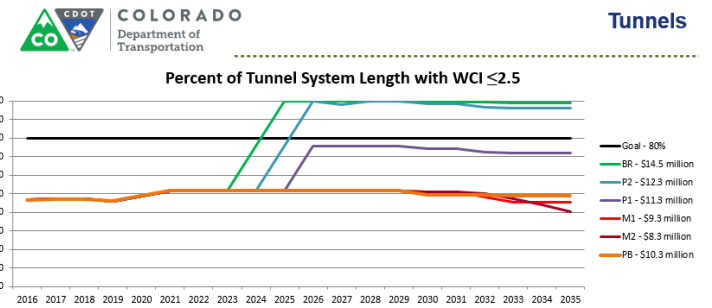
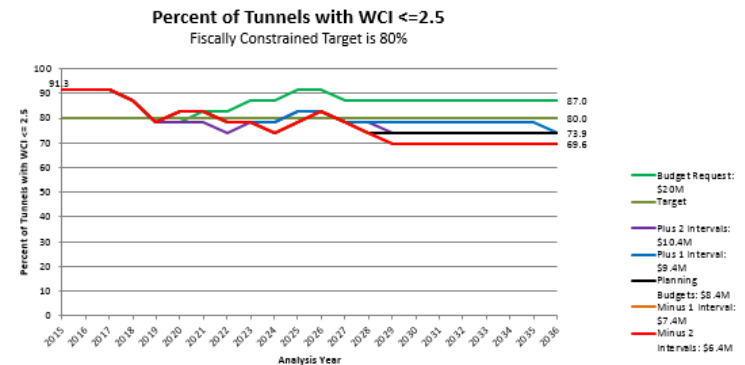
Table 6: Civil Criticality

Sign Elements		
Element	NTIS/*CTIIM Number	Criticality
<b>Variable Message Board</b>	10890	5
<b>Lane Signal</b>	10910	5

Table 7: Sign Criticality

# Tunnel Asset Management

- Performance Metric Evolution
  - 2014-15
    - **Key components of fire/life safety must not exceed 100% of useful life, based on manufacturer's specifications, condition inspections and maintenance history.**
  - 2015-16
    - **Percentage of tunnels with all elements in equal or better condition than 2.5. (performance at 91%)**
  - Current Metrics and Performance Target
    - **Percent of network tunnel length with all elements in equal or better condition than 2.5 Weighted Condition Index. (performance at 52%)**



# Tunnel Asset Management

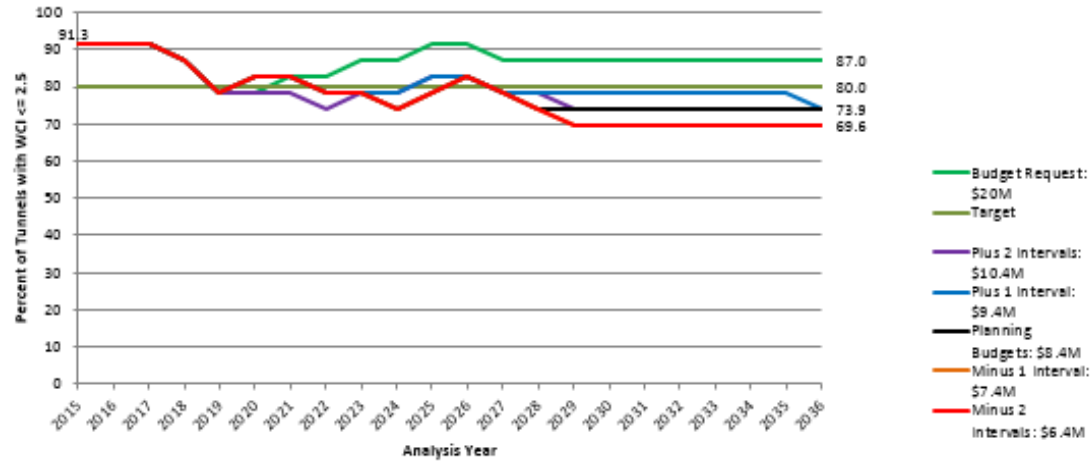
- Performance Metric Comparison

- **By Tunnel – 91.3%**

- **By Tunnel System Length – below 50%**

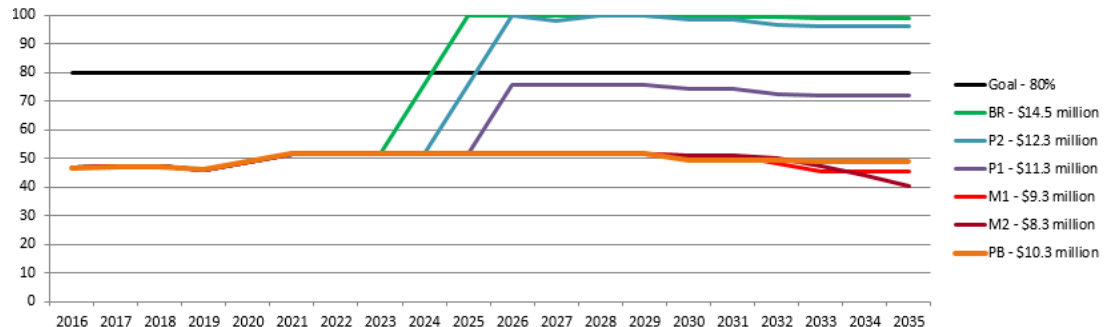
- **Closer to the true need!**

Percent of Tunnels with WCI  $\leq 2.5$   
Fiscally Constrained Target is 80%



Tunnels

Percent of Tunnel System Length with WCI  $\leq 2.5$



# Tunnel Asset Management

1	Name	AAD	Age	Expected Life	CS1	CS2	CS3	CS4	ELEMENT_NUMBER	Element Name	Tunnel_Name
2	H-03-BT_LIG_L_10600	17400	29	20	0	0	1	0	LIG_L_10600	Tunnel Lighting System	Beavertail WB
3	F-13-Y_MEC_E_10400	31000	42	40	0	0	0	1	MEC_E_10400	Emergency Generator	Eisenhower (EJMT WB)
4	F-15-AY_STR_L_10003	13300	64	50	0	23893	8837	0	STR_L_10003	Shotcrete Liner	Clear Creek #1
5	F-08-AT-	8000	26	75	30687	13087	1354	0	STR_L_10001	Cast-in-place Liner	Reverse Curve
6	F-13-X_SIG_V_10890	31000	14	15	0	0	12	0	SIG_V_10890	Variable Message Boards	Johnson (EJMT EB)
7	F-13-X_SAF_O_10800	31000	20	15	0	0	1	0	SAF_O_10800	Tunnel Ops and Security	Johnson (EJMT EB)
8	F-13-Y_SAF_O_10800	31000	12	15	0	0	1	0	SAF_O_10800	Tunnel Ops and Security	Eisenhower (EJMT WB)

Continued

1	Tunnel_Name	Year	Treatment	FinCost
2	Beavertail WB	2016	tunnel_elem_Major_Repair	\$ 500,000.00
3	Eisenhower (EJMT WB)	2016	tunnel_elem_Major_Repair	\$ 1,500,000.00
4	Clear Creek #1	2016	tunnel_elem_Minor_Repair	\$ 2,209,250.00
5	Reverse Curve	2016	tunnel_elem_Major_Repair	\$ 677,000.00
6	Johnson (EJMT EB)	2016	tunnel_elem_Major_Repair	\$ 276,000.00
7	Johnson (EJMT EB)	2016	tunnel_elem_Major_Repair	\$ 179,220.00
8	Eisenhower (EJMT WB)	2016	tunnel_elem_Major_Repair	\$ 178,860.00

Model output gives a list of recommended treatments for tunnel elements.

# Tunnel Asset Management

- Recommendation List and Heat Map Display

NTIS Elements

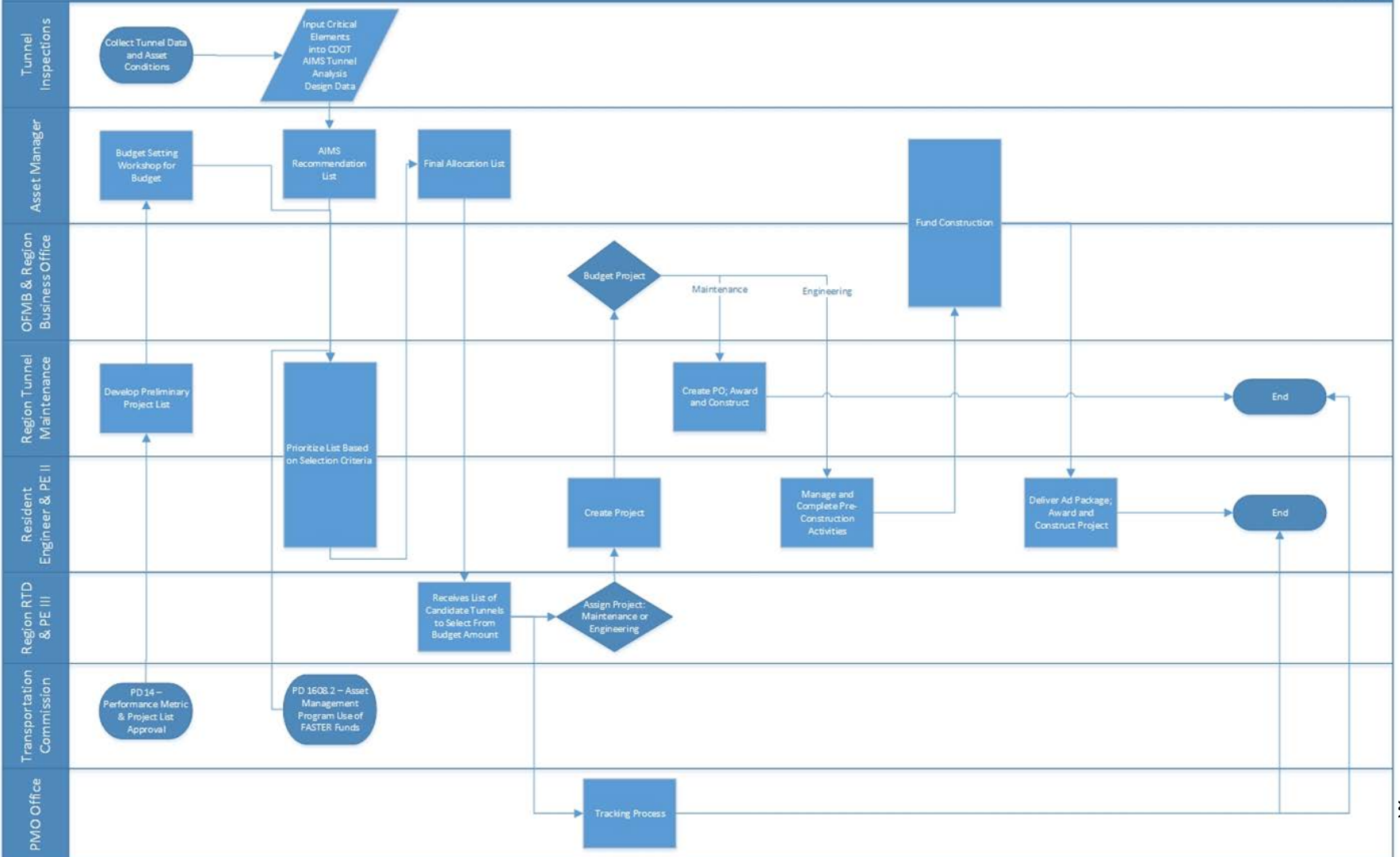
Element Num	Element Name	Tunnel_Name	FirstMajo	Secondl	SecondMajor	After_2016	After_2017	After_2018	After_2019	After_2020
SAF_P_10700	Fire Protection System	Hanging Lake EB	2016	2036	\$ 939,909	1.000	1.059	1.122	1.187	1.255
SAF_P_10700	Fire Protection System	Hanging Lake WB	2016	2036	\$ 939,909	1.000	1.059	1.122	1.187	1.255
ELE_P_10503	Primary Transformers	Johnson (EJMT EB)	2016	2037	\$ 46,888	1.000	1.050	1.101	1.154	1.207
ELE_P_10503	Primary Transformers	Eisenhower (EJMT WB)	2016	2037	\$ 46,888	1.000	1.050	1.101	1.154	1.207
SAF_D_10650	Fire Detection System	Hanging Lake EB	2017	2029	\$ 241,295	2.000	1.000	1.084	1.171	1.261
LIG_L_10600	Tunnel Lighting System	Beavertail WB	2017	2036	\$ 29,450	3.000	1.000	1.080	1.159	1.237
ELE_M_10505	Motor Controls Center	Johnson (EJMT EB)	2017	2037	\$ 293,222	2.500	1.000	1.050	1.101	1.154
SIG_L_10910	Lane Usage Signals	Hanging Lake WB	2017	2031	\$ 1,520	2.200	1.000	1.084	1.171	1.261
SAF_D_10650	Fire Detection System	Hanging Lake WB	2017	2029	\$ 241,295	2.000	1.000	1.084	1.171	1.261
SIG_L_10910	Lane Usage Signals	Hanging Lake EB	2017	2031	\$ 1,520	2.200	1.000	1.084	1.171	1.261
ELE_M_10505	Motor Controls Center	Eisenhower (EJMT WB)	2017	2037	\$ 293,222	2.500	1.000	1.050	1.101	1.154
SIG_V_10890	Variable Message Boards	Hanging Lake EB	2017	2036	\$ 4,082	2.143	1.000	1.138	1.266	1.386
SIG_V_10890	Variable Message Boards	Hanging Lake WB	2017	2036	\$ 4,082	2.143	1.000	1.138	1.266	1.386
LIG_L_10600	Tunnel Lighting System	Beavertail EB	2017	2036	\$ 28,979	3.000	1.000	1.080	1.159	1.237
SAF_O_10800	Tunnel Ops and Security	Wolf Creek	2017			4.000	1.000	1.094	1.177	1.248
CIV_T_10161	Traffic Barrier	Johnson (EJMT EB)	2018			1.564	1.604	1.000	1.035	1.071
CIV_T_10161	Traffic Barrier	Eisenhower (EJMT WB)	2018			1.211	1.249	1.000	1.035	1.071
ELE_E_10500	Electrical Distribution System	Eisenhower (EJMT WB)	2019			3.000	3.045	3.088	0.985	1.020
ELE_E_10500	Electrical Distribution System	Johnson (EJMT EB)	2019			3.000	3.045	3.088	0.985	1.020
STR_L_10003	Shotcrete Liner	Clear Creek #5	2020			3.090	3.131	3.170	3.206	0.982
STR_L_10003	Shotcrete Liner	Boulder Canyon	2020			1.561	1.607	1.652	1.698	1.413
STR_L_10003	Shotcrete Liner	Clear Creek #1	2020			2.270	2.317	2.364	2.409	1.598
STR_L_10003	Shotcrete Liner	Clear Creek #6	2020			3.019	3.064	3.105	3.144	0.981
STR_L_10003	Shotcrete Liner	Clear Creek #3	2020			1.420	1.467	1.514	1.561	1.431
STR_L_10003	Shotcrete Liner	Clear Creek #2	2020			1.350	1.397	1.443	1.489	1.307
LIG_L_10600	Tunnel Lighting System	Clear Creek #1	2021	2031	\$ 665,123	2.000	2.077	2.143	2.201	2.252
ELE_E_10500	Electrical Distribution System	Wolf Creek	2021			1.000	1.035	1.071	1.108	1.144

# Project Selection

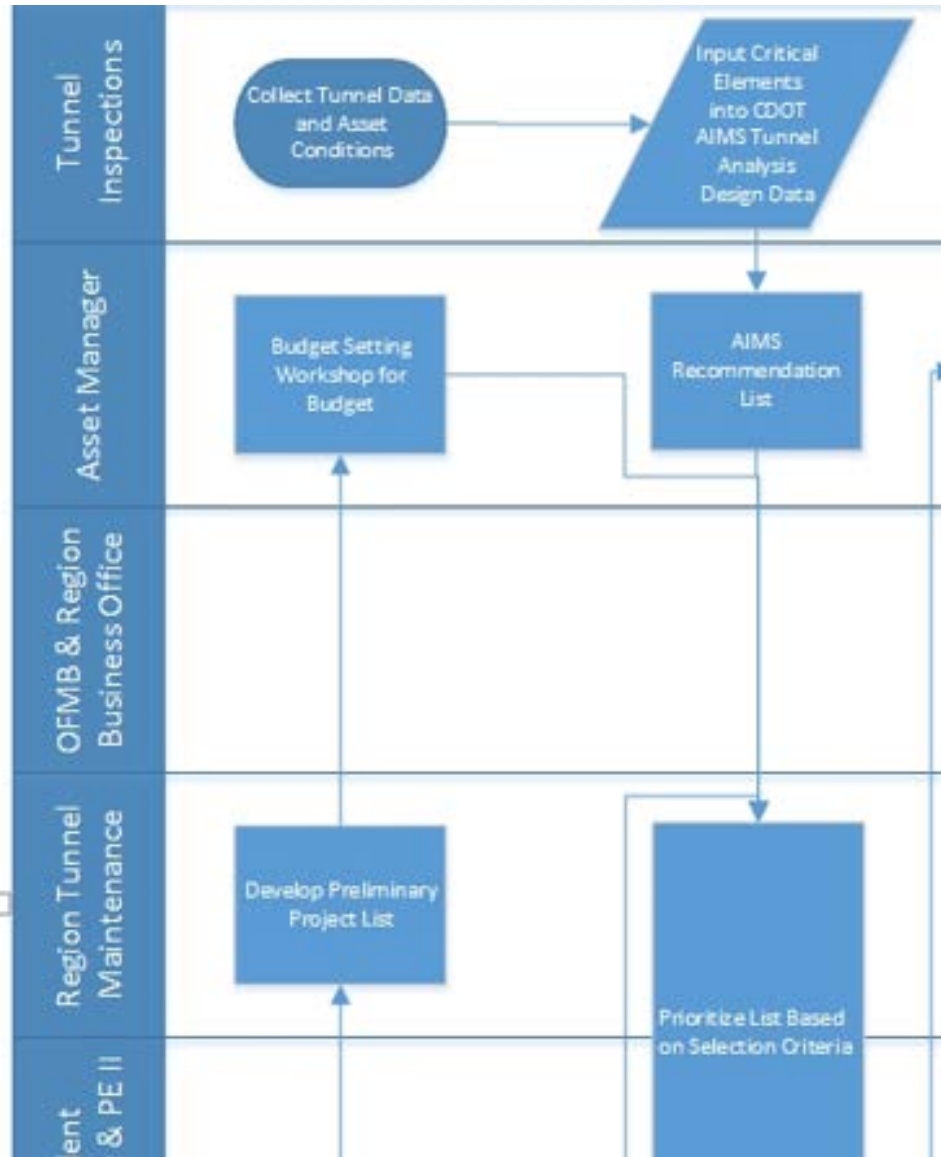
Tunnel Asset Management – Project Selection Process

May 2, 2016

Version 5.2



# Project Selection



- Condition Data
- Budget
- Model Run
- Project List

# Project Selection - Workshop

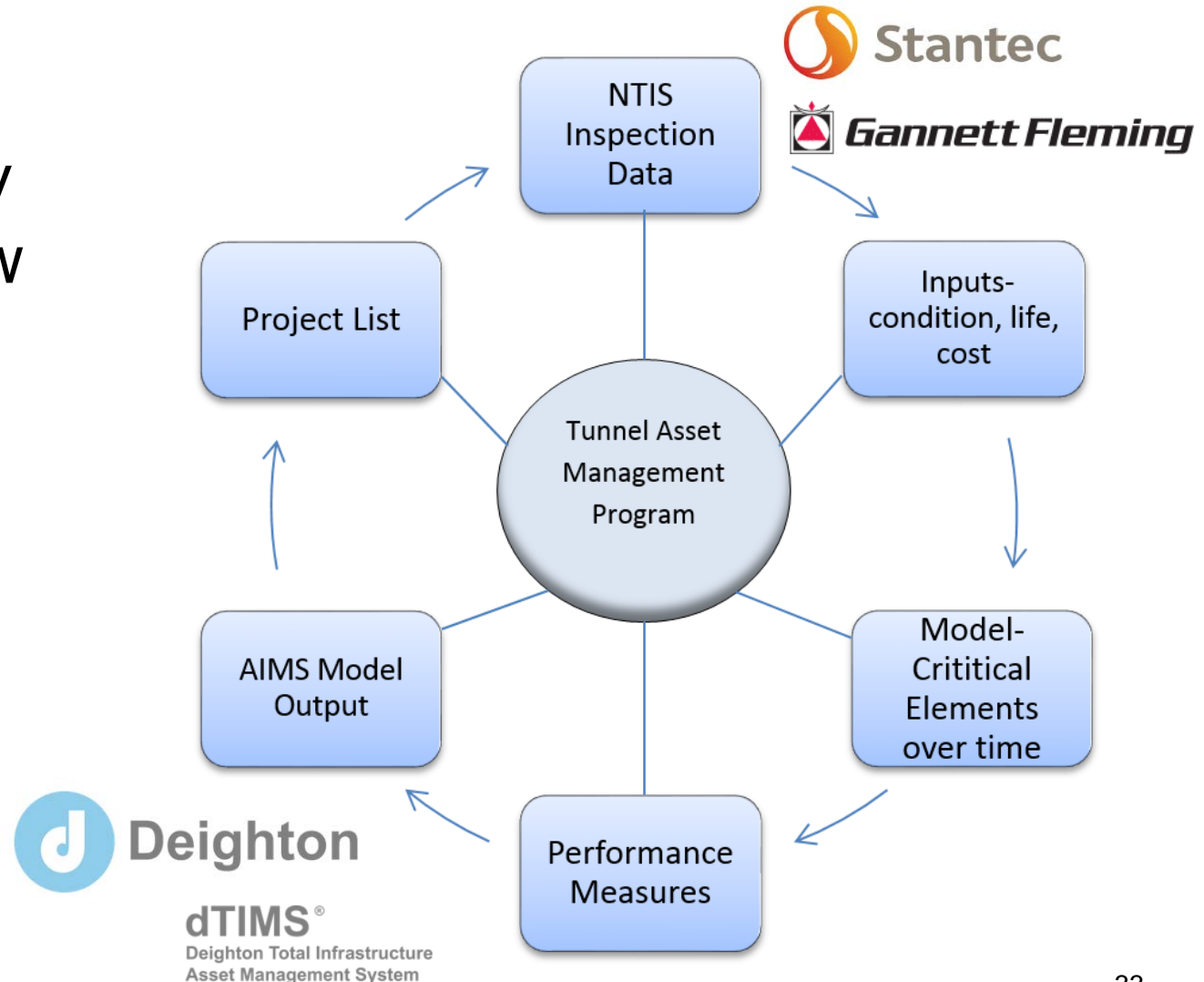
## **NCHRP 14 – 27 GUIDE FOR THE PRESERVATION OF HIGHWAY TUNNEL SYSTEMS**

- NCHRP 14-27 workshop – Fall 2017
- Volunteered to test



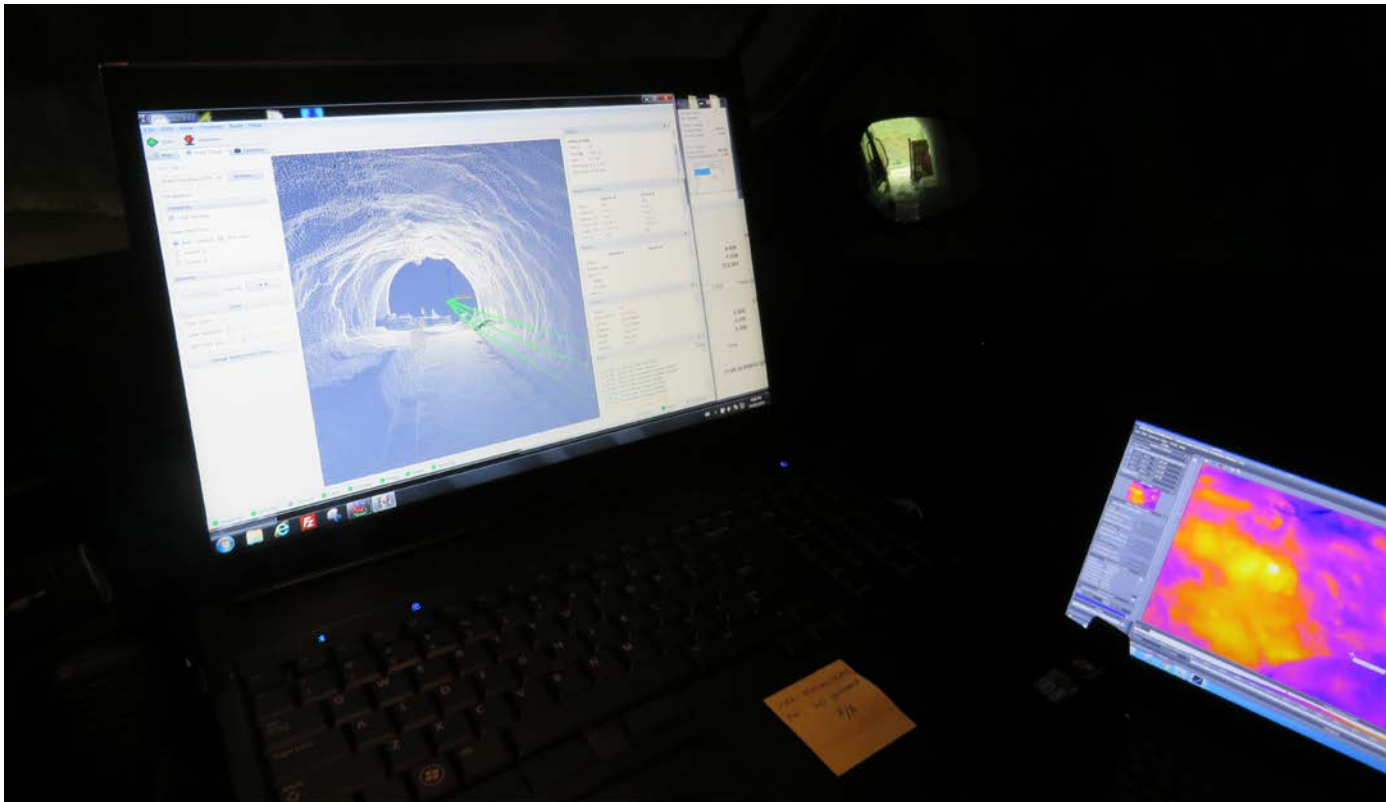
# Tunnel Asset Management

- Complete Cycle every year as new data is collected.



# Next Step for R06G

- Complete additional tunnels
- Complete Final Report



# CDOT 2017 Field trip

- 10 tunnel tour
- Field trip to tunnel No. 4
- Continue on to Eisenhower/ Johnson Tunnel
- Passing through new Veteran's Memorial Tunnel (2-lane to 3-lane expansion project)



# Thank you

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