NCHRP Tunnel Research Updates for T-20

Waseem Dekelbab, PhD, PE, PMP

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Saratoga Springs, New York
April 20, 2015
<table>
<thead>
<tr>
<th>Project</th>
<th>Title</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-89</td>
<td>Recommended AASHTO LRFD Tunnel Design and Construction Specifications ($700K)</td>
<td></td>
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<tr>
<td>20-59(47)</td>
<td>Emergency Exit Signs and Marking Systems for Highway Tunnels ($200K)</td>
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<tr>
<td>20-07 Task 363</td>
<td>Recommended AASHTO Guidelines for Emergency Ventilation Smoke Control in Roadway Tunnels ($50K)</td>
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OBJECTIVE:

- Develop stand-alone recommended design and construction specifications for highway tunnel systems.
- Consideration shall be given to safety and operations, maintenance, and inspection of tunnel systems.
- The research will produce design and construction specifications with commentary in the format of the AASHTO LRFD Bridge Design Specifications.
**PROJECT PHASES:**

- **Phase I**—Detailed Outline for Stand-Alone Specifications
- **Phase II**—Sample Section Specification
- **Phase III**—Specifications Development
- **Phase IV**—Final Products
  1. Revised specification, commentary, and flowcharts after consideration of panel’s comments.
  2. A recommended implementation plan for the tunnel specifications.
  3. A final report that documents the entire research effort.
1. Project Objective
2. Tunnel Preservation Planning Process
3. Prioritization Method
   - Level of Service (LOS)
   - Cost Effectiveness
   - Risk-Based Urgency
   - Measure of Effectiveness
   - Prioritization
4. Funding and Staffing
PROJECT OBJECTIVE

TO DEVELOP A GUIDE:

- Catalog of Preservation Actions
- Quantify the Benefits of Preservation Actions
- Provide Decision-Making Tools to Optimize Tunnel Preservation Actions
- Method to Determine Levels of Funding and Staffing to Achieve Agency Goals and Objectives
TUNNEL PRESERVATION is actions or strategies that prevent, delay or reduce deterioration of tunnels or tunnel systems, restores the function of existing tunnels, keeps tunnels and their systems in good condition and extends their life. Tunnel preservation may include preventive maintenance, cyclical preventive maintenance (activities on a pre-determined interval), condition-based preventive maintenance, and rehabilitation.
Selection of Agency Levels of Service (Goals and Objectives)

- **Reliability** - The ability to keep the tunnel open and operational
- **Safety** - To maintain safe conditions for the traveling public and workers
- **Security** - To reduce the vulnerability to technological or natural hazards
- **Preservation** - To increase the remaining life of the asset
- **Quality of Service** - To improve the experience for the driving public
- **Environment** - To reduce the impacts or potential for environmental impacts
IDENTIFY PRESERVATION ACTIONS

Example: An agency has identified the following preservation actions that it must evaluate and prioritize based on most recent inspections and evaluations of existing systems.

1. Ventilation upgrade to meet NFPA 502. (Tunnel #1)
2. Install new LED lights. (Tunnel #1)
3. CO System - Repair to operating condition. (Tunnel #2)
4. Repair active leak in ceiling. (Tunnel #4)
5. Remove existing concrete tunnel ceiling. (Tunnel #6)
MEASURE OF EFFECTIVENESS

Agency LOS + Cost Effectiveness + Risk Based Urgency = Overall Measure of Effectiveness

- Impact of Preservation Action
- Life Cycle Cost
- ADT
- Condition
- Remaining Life
- Risk of Unplanned Events
- Regulatory Req'mts
Measure of Effectiveness

35% + 20% + 45% = 100%

Agency LOS + Cost Effectiveness + Risk Based Urgency = Overall Measure of Effectiveness

Weights for each score assigned by owner

Impact of Preservation Action

Life Cycle Cost

ADT

Condition

Remaining Life

Risk of Unplanned Events

Regulatory Req’mts

35% + 20% + 45% = 100%
## Measure of Effectiveness

<table>
<thead>
<tr>
<th>Preservation Action</th>
<th>Tunnel #</th>
<th>LOS Score</th>
<th>Cost Effectiveness Score</th>
<th>Risk-Based Urgency Score</th>
<th>Measure of Effectiveness Score</th>
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</thead>
<tbody>
<tr>
<td>Ventilation upgrade to meet NFPA 502</td>
<td>1</td>
<td>66.0</td>
<td>1.9</td>
<td>80</td>
<td>59.5</td>
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<tr>
<td>Install new LED lights</td>
<td>1</td>
<td>78.0</td>
<td>2.4</td>
<td>30</td>
<td>41.3</td>
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<tr>
<td>CO System – Repair to operating condition.</td>
<td>2</td>
<td>63.2</td>
<td>100.0</td>
<td>70</td>
<td>73.6</td>
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<tr>
<td>Repair active leak in ceiling</td>
<td>4</td>
<td>74.6</td>
<td>100.0</td>
<td>70</td>
<td>82.7</td>
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<tr>
<td>Remove existing concrete tunnel ceiling</td>
<td>6</td>
<td>66.0</td>
<td>2.3</td>
<td>100</td>
<td>71.6</td>
</tr>
</tbody>
</table>
Prioritization
Factors Affecting Final Prioritization:

- Owners may choose “low hanging fruit” as top priority
- Internal staffing resources availability
- Plan PA’s in accordance with Capital Plan Budgets
- Group PA’s in one tunnel or regionally to minimize disruptions
- Group PA’s to be performed in one contract (i.e. mechanical) at multiple tunnels
# Prioritization

<table>
<thead>
<tr>
<th>Preservation Action</th>
<th>Tunnel #</th>
<th>LOS Score</th>
<th>Cost Effectiveness Score</th>
<th>Urgency Score</th>
<th>Measure of Effectiveness Score</th>
<th>Calculated Priority</th>
<th>User Defined Priority</th>
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<tbody>
<tr>
<td>Ventilation upgrade to meet NFPA 502</td>
<td>1</td>
<td>66.0</td>
<td>1.9</td>
<td>80</td>
<td>59.5</td>
<td>4</td>
<td>3</td>
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<tr>
<td>Install new LED lights</td>
<td>1</td>
<td>78.0</td>
<td>2.4</td>
<td>70</td>
<td>41.3</td>
<td>5</td>
<td>5</td>
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<tr>
<td>CO System – Repair to operating condition.</td>
<td>2</td>
<td>63.2</td>
<td>100.0</td>
<td>70</td>
<td>72.6</td>
<td>2</td>
<td>2</td>
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<tr>
<td>Repair active leak in ceiling</td>
<td>4</td>
<td>74.6</td>
<td>100.0</td>
<td>70</td>
<td>82.7</td>
<td>1</td>
<td>1</td>
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<tr>
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<td>6</td>
<td>66.0</td>
<td>2.3</td>
<td>100</td>
<td>71.6</td>
<td>3</td>
<td>4</td>
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</table>

Owner has ability to change final priority

- Owner has ability to change final priority.
Funding to Achieve Agency Goals
## Funding

<table>
<thead>
<tr>
<th>User Priority</th>
<th>Preservation Action</th>
<th>Tunnel #</th>
<th>Total Score</th>
<th>Total Project Cost</th>
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<tbody>
<tr>
<td>1</td>
<td>Repair Active Leak in Ceiling</td>
<td>4</td>
<td>96.3</td>
<td>$11,000</td>
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<tr>
<td>2</td>
<td>CO System - Repair to Operating Condition</td>
<td>2</td>
<td>95.9</td>
<td>$35,200</td>
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<tr>
<td>3</td>
<td>Ventilation upgrade to meet NFPA 502</td>
<td>1</td>
<td>89.3</td>
<td>$6,270,000</td>
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<tr>
<td></td>
<td>Remove existing concrete tunnel ceiling</td>
<td>6</td>
<td>73.2</td>
<td>$9,064,000</td>
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<tr>
<td></td>
<td>Install New LED Lights</td>
<td>1</td>
<td>72.2</td>
<td>$3,967,766</td>
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</table>

**Top Down Funding**

Yr. 1 Budget for Tunnel Preservation = $7 M.

Yr. 2 Budget = $10 M.

Total: $6.3 M

Total: $9.1 M

Total: $6.3 M

Total: $9.1 M
Staffing Needs to Achieve Agency Goals
### Staffing

<table>
<thead>
<tr>
<th>User Priority</th>
<th>Preservation Action</th>
<th>Tunnel #</th>
<th>Total Agency Labor Cost ($)</th>
<th>No. of FTE</th>
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<tbody>
<tr>
<td>1</td>
<td>Repair Active Leak in Ceiling</td>
<td>4</td>
<td>$1,000</td>
<td>0.01</td>
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<tr>
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<td>2</td>
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<tr>
<td>3</td>
<td>Ventilation upgrade to meet NFPA 502</td>
<td>1</td>
<td>$570,000</td>
<td>2.7</td>
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<tr>
<td>4</td>
<td>Remove existing concrete tunnel ceiling</td>
<td>6</td>
<td>$800,000</td>
<td>3.8</td>
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<tr>
<td>5</td>
<td>Install New LED Lights</td>
<td>1</td>
<td>$340,000</td>
<td>1.6</td>
</tr>
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</table>

**Funding**

Agency labor is estimated for each PA:

- Agency oversight or labor?
- What % of PA cost is labor?
- Use this to estimate agency labor

Total: 3 FTE

Total: 4 FTE

Total: 4 FTE
Communicating the Needs and Benefits of the Preservation Actions
COMMUNICATING THE NEEDS AND BENEFITS

- 5 PAs will Significantly or Greatly Impact Safety...............................$ 14.4M
- 2 PAs will Significantly or Greatly Improve Reliability........................$ 8.3M
- 2 PAs will Greatly Improve Quality of Service.................................$ 10.8M
- 4 PAs will Improve Assets that are in Poor or Severe Condition...........$ 10.8M
Next Steps

- Final Guide
- Final Report
- Implementation?
NCHRP 20-59(47): Emergency Exit Signs and Marking Systems for Highway Tunnels
PROJECT OBJECTIVES

- Determine messages and media to get drivers to leave vehicles if necessary.
- Determine best sign and marking system designs for guiding pedestrians to tunnel exits.
- Determine most visible sign and marking materials and technologies for tunnel conditions.
HUMAN FACTORS STUDIES

- Focus Groups
- Expert Panel
- Tunnel simulation - in-vehicle
  - Response to emergency situation/messages
- Tunnel simulation - on foot
  - Comprehension of signs and markings
  - Visibility of signs and markings
TUNNEL SIMULATION – IN VEHICLE
TUNNEL SIMULATION – ON FOOT
TEST SIGNS

- Exit sign
- Exit with distance marker
- Exit with left arrow
- Exit with right arrow
- Exit with wheelchair symbol
RM Sign Comprehension

- 48% said “exit” or similar
- 38% guessed a path to follow
- 100% comprehension of meaning
- 100% comprehension of meaning
- 98% comprehension of location
Detection and Legibility Distances – Running Man Exit Distance Signs w/ Ambient Light

- LED - Detection
- LED - Legibility
- PL - Detection
- PL - Legibility

Smoke Opacity vs. Feet

- 0% Smoke Opacity: LED - Detection = 50 feet, LED - Legibility = 45 feet, PL - Detection = 40 feet, PL - Legibility = 35 feet
- 5% Smoke Opacity: LED - Detection = 40 feet, LED - Legibility = 35 feet, PL - Detection = 30 feet, PL - Legibility = 25 feet
- 10% Smoke Opacity: LED - Detection = 30 feet, LED - Legibility = 25 feet, PL - Detection = 20 feet, PL - Legibility = 15 feet
- 15% Smoke Opacity: LED - Detection = 20 feet, LED - Legibility = 15 feet, PL - Detection = 10 feet, PL - Legibility = 5 feet
- 20% Smoke Opacity: LED - Detection = 10 feet, LED - Legibility = 5 feet, PL - Detection = 5 feet, PL - Legibility = 2.5 feet
- 25% Smoke Opacity: LED - Detection = 5 feet, LED - Legibility = 2.5 feet, PL - Detection = 2.5 feet, PL - Legibility = 1.25 feet
Path Markings/Beacons

- Flashing lights preferred over steady lights
- Directional/”traveling” lights preferred over lights flashing in unison
- Audio signal at doorway (“Exit here”) considered helpful at short distances
PROPOSED GUIDE – RESEARCH RESULTS

- Emergency messages/announcements
- Exit signs and markings
- Sign/marking technologies
- Responder training/outreach
- Public outreach/education
NCHRP 20-07 Task 363: Recommended AASHTO Guidelines for Emergency Ventilation Smoke Control in Roadway Tunnels
OBJECTIVE

Develop recommended AASHTO guidelines for emergency ventilation smoke control in roadway tunnels to improve human evacuation and emergency responder safety. As a minimum, the guidelines shall consider:

- Applicable conditions for application of various tunnel ventilation systems and configurations (e.g., full transverse, partial transverse, and longitudinal systems);
OBJECTIVE (CONT.)

- Fan utilization or placement based on tunnel geometrics and gradient;
- Tunnel length and directional traffic flow (i.e. unidirectional or bi-directional flow);
- The relationship between vehicle types and heat release and ventilation requirements;
- Effects of ventilation on tunnel fires and fire size;
- Fire detection and warning systems;
- Actual fire smoke stratification duration and length of stratification in tunnel;
The interaction between firefighting operation and ventilation systems;

Applicability of tunnel vehicle fire suppression system and its applicable conditions;

Practicality of one-button or error proof emergency ventilation (i.e. closed loop ventilation control);

Applicable regulatory standards & guidelines (including national and international).
**TASKS:**

1. Synthesize the literature review and submit a draft of the synthesis no later than 3 months after contract award.

2. Prepare a detailed outline for the recommended AASHTO guidelines for emergency ventilation smoke control in roadway tunnels including annotated description of each section (chapter) and subsection. NCHRP approval will be required before proceeding with the remaining tasks.
TASKS:

3. Develop a draft recommended AASHTO guidelines for emergency ventilation smoke control in roadway tunnels. The guidelines should include procedural processes and QC/QA plans to improve emergency smoke ventilation.

4. Revise the draft proposed guidelines submitted in Task 3 according to the NCHRP project panel comments.
5. Present the proposed guidelines in AASHTO standard interim-revision format to the AASHTO Subcommittee on Bridges and Structures, Technical Committee T-20 Tunnels.

6. Submit a final report describing the entire research effort with the proposed guidelines. Following receipt of the draft final report, the remaining 2 months shall be for NCHRP review and comment and for research agency preparation of the revised final report.