# Development of Tunnel Asset Management (TAM) Program

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**ABSTRACT:** Typical highway infrastructure systems include roadway pavement, drainage systems, tunneling, and other hardware components such as guardrails, traffic signs, and lighting. Tunnels in a highway system have provided significant advantages to overcoming various natural challenges including crossing underneath bodies of water or through mountainous areas. While only a few tunnel failure cases have been reported, the failure rate is likely to increase as these assets age and because agencies have not emphasized tunneling asset management. A tunnel system undergoes a deterioration life cycle pattern that is similar to other infrastructure systems. There are very few agencies in the United States implementing comprehensive tunnel asset management programs. While current tunnel asset management programs focus on inspection, maintenance, and operation safety, there is an increasing need for the development of a comprehensive life cycle tunnel asset management program. This paper describes a conceptual framework for a comprehensive tunnel asset management program. The framework consists of three basic phases including a strategic plan, a tactical plan, and an operational plan to provide better information to the decision makers. The strategic plan is a basic long term approach of tunnel asset management. The tactical plan determines specific objectives and the operational plan actually applies asset management objectives in practice. The information includes operational condition, structural condition, efficiency of the system, emergency response, and life cycle cost analysis for tunnel capital improvement project planning.

*Keywords: Asset Management; Tunnel Asset Management (TAM); Strategic Plan; Tactical Plan; Operational Plan*.

## 1. INTRODUCTION

The capability of tunnels for transportation, water storage, transmission lines, and other activities has increased during the last decade due to limited space, their safe operation, and environmental impact awareness. A road tunnel is a complex infrastructure system compared to other highway assets. It consists of several components such as the tunnel structure, drainage systems, mechanical systems, electrical systems, and emergency systems. One part of the tunnel structure is the tunnel lining, which supports the surrounding ground and provides a safe space for the contents of the tunnel. A water drainage system is required to address surface drainage as well as ground water infiltration, both of which are the main causes of deterioration of various tunnel elements. To provide safety the tunnel's ventilation system, lighting system, and emergency system play an important role. A ventilation system is required to reduce the interior pollution levels. An appropriate lighting system for specific parts of a tunnel is required to avoid the black hole effect for drivers when they enter the tunnel [1]. The emergency systems are utilized to manage and control the risks involved in tunnels.

This complex asset system requires the integration of appropriate engineering and management to bring a high level of service for customers. In Switzerland, about 50% of the highways proposed to be built for the completion of the road network by 2015 would run through tunnels [2]. According to the National Cooperative Highway Research Program (NCHRP), the Asset Management Program (AMP) has called attention to highway infrastructure such as pavement and bridges but not tunnels because many departments of transportation (DOTs) do not have tunnels in their transportation systems, and others built their last tunnels 20 to 30 years ago [3]. Recent incidents, such as the 2006 ceiling collapse and water leak in the I-90 central Artery/Tunnel (CA/T) in Boston, have called attention to the importance of tunnel asset management. According to the U.S. DOT, "Most guideline materials, handbooks, and procedural manuals for the inspection and maintenance of tunnels have been developed by a few proactive tunnel owners. This sporadic ap proach shows much variability in the depth and the breadth of tunnel management procedures" [4]. In addition, several other studies indicate that there is no consistency for inspection and rehabilitation of tunnels among DOTs as noted in a recent study provided by Gannett Fleming, Inc. prepared for AASHTO Technical Committee for Tunnels [5].

A Tunnel Asset Management (TAM) program addresses not only tunnel maintenance, tunnel condition assessment, and risk evaluation, but it also helps to reduce life cycle cost, manage risk effectively, improve the level of safety, and harmonize the objective through a conceptual frame work asset management program plan. This framework consists of three phases including strategic plan, tactical plan, and operational plan.

The strategic plan will define the objective and explain the long-term goal from the owner's prospective. In tunnel assets, the tunnel owner's or tunnel agency's' objectives will be increasing the life cycles of tunnels, minimizing the life cycle cost of tunnels, and increasing the level of services that match customers' expectations. How to reach that goal will be determined in the tactical plan. An asset manager or tunnel manager should be assigned by the tunnel owner or tunnel agency to oversee the tactical plan. The tunnel manager will identify the tunnel's current status, condition and performance, and identify the best practices of life cycle assessment, life cycle cost and risk to prioritize the action list and improve sustainability. Then, an operational plan or functional plan should be developed to determine how to apply the tactical plan.. A tunnel service operator will be responsible to provide personnel, equipment, and new technologies to fit the tactical plan. A tunnel service operator will also be responsible for developing an inspection schedule, traffic control plan, and rehabilitation schedule for each specific tunnel .

## 2. Literature Review Analysis

### 2.1 Available TAM program in the United Stated

The United Stated Department of Transportation (U.S. DOT) defined its typical assets as pavements, structures, tunnels, and hardware when the U.S. DOT created the Office of Asset Management [6]. The U.S. DOT strategic plan for its highway asset management program is well defined. According to the U.S. DOT (1999), "a key feature of asset management is that it requires a statement of explicit, clearly defined goals," which is the main concept of the strategic plan. Figure 1 shows the strategic asset management framework defined by the U.S. DOT [6].

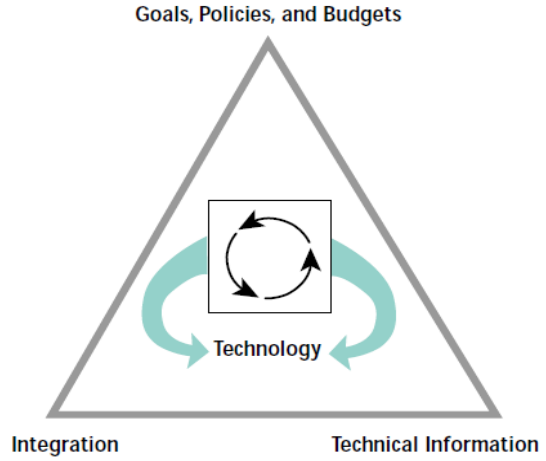


**Figure 1. Strategic Asset Management Framework [6]**

The Federal Highway Administration (FHWA) in conjunction with the Federal Transit Administration (FTA) prepared an inspection, maintenance, and rehabilitation manual to assess physical conditions of tunnel components. This manual was designed to help tunnel owners and agencies in the repair of deficiencies because many tunnels in the United States were more than 50 years old. Signs of deterioration, especially water infiltration, were obvious. The inspection manual introduced the fundamentals of inspection in underground road and rail tunnels, such as inspection of civil/structural systems, mechanical systems, electrical systems, and a variety of other systems. FHWA created a 10 point scale to evaluate each system's condition. The range of numerical rating is from 0 to 9, wherein 0 is the worst condition element and 9 is the best condition situation. This condition code which is shown in Table 1 is a modified format of the Bridge Inspector's Training Manual published by the FHWA [7].

**Table 1. Condition Codes Systems for Highway and Transit Tunnels [7]**

| *Rating* | *Description* |
|---|---|
| 0 | Critical Condition- Structure is closed and beyond repair. |
| 1 | Critical condition - Immediate closure required. Study should be performed to determine the feasibility of repairing the structure |
| 2 | Serious condition - Major repairs are required immediately to keep structure open to highway or rail transit traffic. |
| 3 | Poor condition - Major repairs are required and element is not functioning as originally designed. Severe defects are present. |
| 4 | Shading between "3" and "5." |
| 5 | Fair condition - Minor repairs required but element is functioning as originally designed. Minor, moderate, and isolated severe defects are present but with no significant section loss. |
| 6 | Shading between "5" and "7." |
| 7 | Good condition - No repairs necessary. Isolated defects found. |
| 8 | Excellent condition - No defects found. |
| 9 | Newly completed construction. |

According to the National Cooperative Highway Research Program (NCHRP), Colorado DOT, District of Columbia DOT, Virginia DOT, and Washington State DOT are using the Highway and Rail Transit Tunnel Inspection Manual as a reference, while The Port Authority of New York and New Jersey, and Massachusetts DOTs use their own manuals for tunnel inspection [3]. In addition, the Tunnel Management System (TMS) software has been released with those manuals from the FHWA and the FTA. This software is used to collect and manage tunnel components data. Currently, District of Columbia DOT, Penn DOT, the Pennsylvania Turnpike Commission (PTC), North Texas Toll way Authority, and California DOT use the Bridge Management System (BMS) for their general tunnel inspection. Likewise, Massachusetts DOT uses the bridge inspection form to collect and manage data [3].

Based on the literature review, the U.S.DOT defined its strategic plan based on the integration of goals, policies,

and budget for all highway assets. However, the strategic plan for tunnels is different from bridges, culverts, and pavements due to their complexity. The missing part in tunnel asset management is how tunnel agencies are going to achieve their goals.

FHWA developed the inspection, maintenance, and rehabilitation guideline for tunnels as an operational plan; however, there is no consistency in the application of the guidelines due to lack of information in tactical planning which consists of condition assessment, life cycle cost assessment, and sustainability assessment. In addition, tunnels in several geographical, traffic, and climate situations require different operational approaches for inspection, maintenance, and rehabilitation schedules, as well as traffic control and new technologies for inspection and rehabilitation.

### 2.2 Available TAM Program in European Countries

The Working Group 1(WG1) of the Permanent International Association of Road Congress (PIARC) provided the guideline for tunnel management based on the experience of ten European countries engaged in a tunnel management program. According to PIARC, "the goal of the tunnel maintenance is to ensure safe driving for the public by keeping the tunnel at the designed safety standard" [8]. The defined Tunnel Management System (TMS) in the guideline consists of 1) plan the necessary operation or maintenance work including program and material requirements, 2) generate cost analyses to help management provide budget, quality control and historical maintenance records for works undertaken in the tunnel, 3) optimize tunnel maintenance activities and 4) provide technical feedback to management based on the tunnel and installed systems as shown in Figure 2 [8].

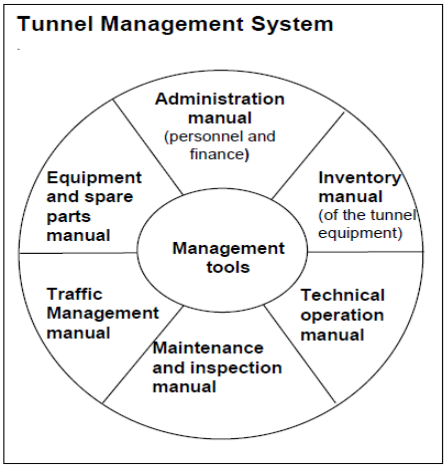


**Figure 2. Tunnel Management System [8]**

Regarding maintenance, PIARC recommended two sub-categories: 1) preventive maintenance which keeps the tunnel systems in a good and safe condition, and 2) corrective maintenance which is carried out after systems have failed as shown in Figure 3.

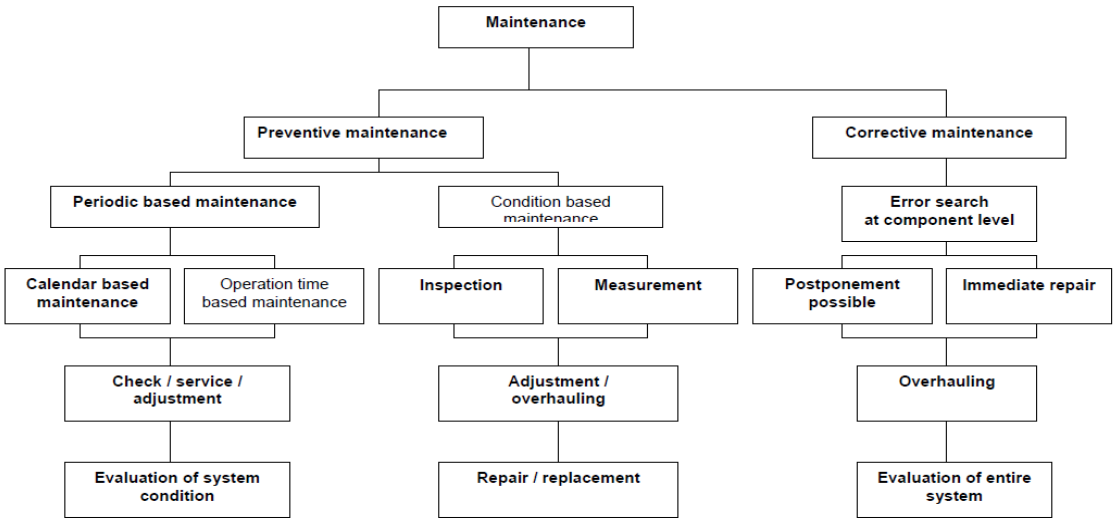


**Figure 3. Comprehensive Tunnel Maintenance plan [8]**

### 2.3 Available TAM Program in Australia and New Zealand

In 2012, the New Zealand Transport Agency (NZTA) published the State Highway Asset Management Plan 2012-2015. This plan was prepared to provide long term capital and operational funding and also provide a robust 10-year program. One of the approaches of this plan is to improve major tunnels and upgrade the tunnel management system. This plan can be classified as a strategic plan for highway assets (such as tunnels) because it contains defined goals during a period of time.
Australia and New Zealand developed a guideline for operation and maintenance of its road tunnels. This manual covers organizational framework, risk analysis, traffic management, incident management, human factors, training, and environmental aspects of an asset management program [9].

The New Zealand Office of General Audit study in 2010 found a considerable amount of missing data in condition assessment, especially for structures such as bridges and tunnels. Based on this study, NZTA determined a routine condition assessment program for its highway pavement and road surfaces, and a regular inspection program for structural assets such as bridges and tunnels. Currently, the regional bridge consultant inspects tunnels in New Zealand. The inspection frequency is similar to the bridge inspection. The New Zealand Office of General Audit recommended to the NZTA to "review its structural inspection policy to ensure that there is a consistent and appropriate approach to the issues and risks associated with tunnels" [10].
Contrary to the United States, Australia and New Zealand have developed a more comprehensive TAM program which covers risk analysis, traffic management, incident management, environmental issues, and a training program for tunnel users. These factors were not mentioned in the FHWA tunnel management system practices.

### 2.4 Available TAM program in Japan

Tunnels play an important role in the transportation network in Japan as shown in Figure 4 [11]. Japan has started to improve the safety of its road tunnels, revising technical standards, improving emergency facilities, and promoting education for road users since the tragic fire accident of the Nihonzaka Tunnel in 1979.

Road tunnel maintenance in Japan involves a multistep process which includes inspection and examination to detect deformations, followed by evaluation to determine the causes of the detected deformations. Repair and reinforcement are utilized as preferred corrective methods depending upon the deformation, based on the Manual for Maintaining Road Tunnels published by the Japan Road Association in 1993. This manual can be classified as a tactical plan for tunnel agencies to determine how to manage the several systems in the tunnels. The Manual for Maintaining Road Tunnels in Japan also defines the risks based analysis in terms of deformation, urgency of taking countermeasures, safety of users and vehicles, structural safety, and effects of maintenance work. The risk analysis for the tunnels was defined into four types, as shown in Table 2 [11].

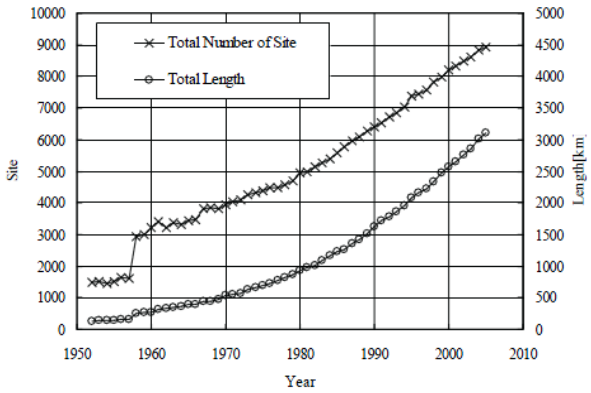


**Figure 4. Tunnel Inventory in Japan [11]**

Current practice to provide tunnel safety are: 1) periodic drills which include testing of fire detection devices and alarm transmissions, 2) evaluating and testing of ventilation systems; 3) providing education for road tunnel users; and 4) providing cooperation between other relevant organizations. For example, the Shinjuku Tunnel has been operated with emergency equipment such as emergency telephones, fire detectors, fire plugs, hydrants, observation equipment, water sprinkler systems, smoke exhaust equipment, and radio communication auxiliary equipment [12].

The Manual for Maintaining Road Tunnels in Japan also defines the risks based analysis in terms of deformation, urgency of taking countermeasures, safety of users and vehicles, structural safety, and effects of maintenance work. The most frequent problems of tunnel deterioration in Japan are cracks, and loosening / exfoliation of lining concrete.

To solve these problems, Mashimo and Ishimura recommended installing some advanced technology such as photographing the surface of the tunnel lining with a laser beam and Compact Camera Modules (CCM) cameras inside the tunnel. The captured images are analyzed and then expanded diagrams of the cracks are developed [12]. This study mentioned some technologies to monitor and provide feedback from inside the tunnel to the tunnel manager which can be classified as an operational plan or functional plan.

**Table 2. Risk Analysis of Tunnels in Japan**

| *Type* | *Description* |
|---|---|
| 3A | Seriously deformed. Urgent measures are needed since users and vehicles are at risk. |
| 2A | Deformed. Urgent measures are needed since deformation may progress and endanger user and vehicles. |
| A | Deformed. Close monitoring and systematic measures are needed since the deformation may endanger users and vehicles in future. |
| B | Not deformed or slightly deformed. The deformation has no effect on users and vehicles, but the tunnel needs to be monitored. |

Japan TAM program can be a good reference in principles and practices of TAM program; however, some improvement is required for its tactical and operational plan. At the first step it defined safety level of service as significant factors in strategic plan for tunnels due to several accidents in tunnels. Compared to the U.S. TAM program, Japan incorporated non-destructive technologies for inspection, and rehabilitation techniques in their operational plan.

## 3. Tunnel Asset Management Framework

Highway asset management is a broad topic and each component of this complex asset requires planning, designing, developing, and executing a comprehensive asset management program. According to the International Infrastructure Management Manual [13], asset management is "the combination of management, financial, economic, engineering, and other practices applied to physical assets with the objective of providing the required level of service in the most cost-effective manner." Tunnel Asset Management (TAM) is an organized approach to managing the overall operation of tunnels to minimize life cycle cost as well as to provide a high level of service and safety for customers.

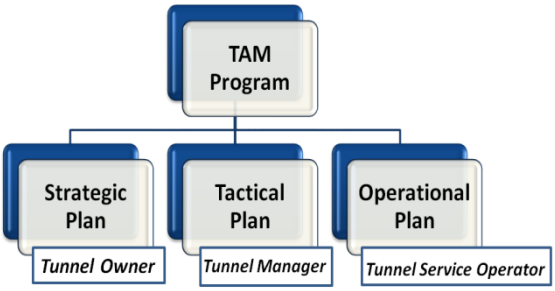


**Figure 5. Tunnel Asset Management Components**

### 3.1 Strategic Plan

The strategic plan is basically an organized process of defining long-term goals, directions, and making decisions to pursue those goals. The first cycle of TAM is defined as a strategic plan which should clearly determine the mission and objectives. The tunnel agencies should define the mission statement based on the long-term goal. The main goal of tunnel agencies for implementing asset management plans is to increase the life cycle of the tunnel, while reducing the life cycle cost of it. Based on this goal, tunnel agencies should define a timeline, such as 30 years, and set benchmarks to measure attainments.
The tunnel asset owner will appoint a committee board to oversee this process and is responsible for communicating with the committee board members to keep them involved in the decision making process. In addition, the important role of the tunnel owner is to provide financing for the tunnel asset management process based on prioritization and estimation of cost, which will be provided by the tunnel manager from the tactical plan. According to IIMM, the long-term financial plan should contain all cost elements explored under life cycle costing [13]. The basic components of a financial forecast should include: 1) operational, maintenance, renewal, and rehabilitation costs; 2) estimates for specific periods of time, for example 20 years; 3) provable unit costs; and 4) annual updates.


**Figure 6. Strategic Plan**

### 3.2 Tactical Plan

The tactical plan demonstrates how the strategic plan will be implemented. The long term strategic plan will be split into to several short term tasks in the tactical plan. The tunnel manager is responsible for providing the tactical plan for the tunnel owner based on defining the strategic plan.

The main concept of the tactical plan consists of providing an inspection plan for each tunnel component including structural, mechanical, electrical, drainage, and emergency systems, "best practice" condition assessment, life cycle cost analysis, a training program for the tunnel users (drivers) as well as tunnel personnel, and improved sustainability of tunnels through life cycle analysis, and a reduction of its carbon foot print and social impact.

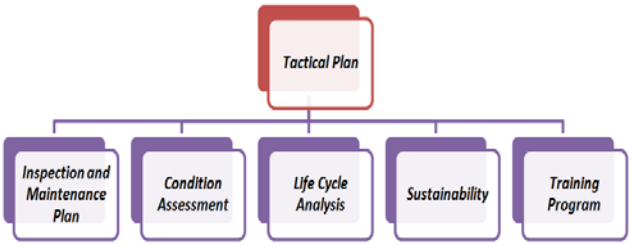


**Figure 7. Tactical Plan**

The inspection and data acquisition process is the first step in a tactical plan. According to the FHWA, inspection and data gathering is an important factor for tunnel management [6]. The tunnel manager should follow the inspection manual for each component of the tunnel such as structural systems, mechanical systems, electrical systems, and emergency systems. The gathered data will be evaluated, categorized and scored as shown in Table 3 based on risk analysis. This figure will help the

tunnel manager to prioritize each tunnel element for the rehabilitation and renewal process. The tunnel manager should follow the tunnel rehabilitation and renewal manual for each component. Afterwards, the cost estimation for rehabilitation and renewal activities will be provided and submitted to the tunnel owner to provide the financial assets.

**Table 3. Condition Assessment of Tunnel**

| Rank | Condition |
|---|---|
| 1 | Very Good Condition-Regular Maintenance Required |
| 2 | Minor Defects-Specific parts needs Maintenance |
| 3 | Major Defects-Significance Maintenance Required |
| 4 | Requires Renewal-Significant Renewal required |
| 5 | Tunnel Unserviceable-Asset needs to be closed |

Life cycle cost assessment (LCCA) is another output of the tactical plan. The tunnel manager should analyze the life cycle cost of the tunnel to the owner to determine funding, with the data based on an economic evaluation which addresses the total cost of owning and operating the tunnel for the defined period of time. The LCCA varies from tunnel to tunnel because it depends on the method of construction and various installed equipment.

The tunnel manager is also responsible for developing a sustainable approach for the tunnel in the tactical plan. To reach the sustainability goals, the manager should consider life cycle analysis, social impact, and carbon footprint issues.. Moreover, by developing renewable energy in the last decade, the tactical plan should be consider a tool to reach sustainability, reduce its carbon footprint, and reduce the cost associated with the electrical, mechanical, and emergency systems in the tunnel.

Providing a safe tunnel environment cannot be limited to the installation of safety facilities and emergency equipment. According to the Austroads guide To the Road Tunnels, “Investigation into previous tunnel incidents and emergencies, plus other research into human behavior, has demonstrated that people do not necessarily behave, or respond rationally during stressful or life threatening emergencies” [9]. So, the tunnel manager should constantly provide the awareness of appropriate behavior of tunnel users by supporting training and educational programs.

### 3.3 Operational Plan

The operational plan or functional plan provides instructions of how the tactical plan will be implemented in the tunnel field. After determining the inspection, maintenance, renewal, and rehabilitation process, the operational plan will determine how the tactical plan can best be implemented. The tunnel service operator is responsible for identifying technology providers to inspect, maintain, renew, and rehabilitate each structural, mechanical, electrical, and emergency element, based on the recommendation of the tunnel manager and the tactical plan. The tunnel service operator can develop a detailed operational plan for each element of the tactical plan while the tactical plan is being developed. The situation and condition of each tunnel varies based on its geographical area, amount of traffic, local weather conditions, etc. So the tunnel service operator should develop an operational plan for inspection, maintenance, rehabilitation, and traffic control.

In addition, the tunnel service operator needs to provide new technologies for the inspection and maintenance process and provide detailed feedback of current conditions of tunnel components for the manager to help make informed decisions.

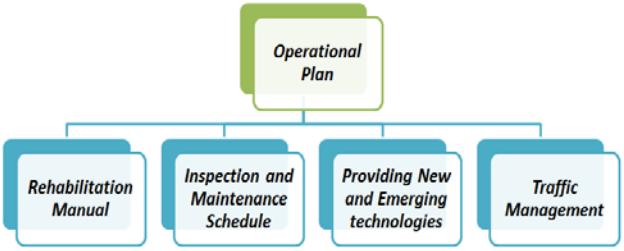


**Figure 8. Operational Plan**

## 4. Conclusion

Tunnels play a vital role in transportation infrastructures. They are high value assets not only because of their high cost of construction, but also due to the complex systems involved and expensive equipment to operate them. Therefore, to maintain and sustain this high value asset, a comprehensive Tunnel Asset Management (TAM) plan is required. According to the recent study by the Gannett Fleming Inc. regarding the best practice of Quality Control/Quality Assurance (QC/QA) for tunnel inspection, “there is no consistency across the country when it comes to tunnels inspection. In addition, there is limited experience and knowledge of tunnel inspection methods with states DOTs [5]. Based on a literature review, there is no consistency for inspection processes among rehabilitation manuals from the FHWA and the FTA. To overcome these barriers, the proposed TAM plan consists of three basic phases: a strategic plan, a tactical plan, and an operational plan. The strategic plan is defined by the tunnel owner and consists of the long term desired approach of the project. It can be classified as having three basic components: provide safety, an appropriate level of service, and a budget.. The tactical plan determines the approach to accomplish the strategic plan. This plan is identified by the asset manager and consists of the short term approach to the strategic plan. The operational or functional plan applies the tactical plan in the tunnel’s asset field. The operational plan provides feedback from the tunnel service providers to the asset manager.

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