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   Determining the True Cost and Benefit for Collecting and Maintaining Non-Road and Non-Bridge Asset Data

2. Author(s)
   Peter R. Stopher and Ruijie "Rebecca" Bian

3. Performing Organization Name and Address
   Department of Civil and Environmental Engineering
   Louisiana State University
   Baton Rouge, LA 70803

4. Sponsoring Agency Name and Address
   Louisiana Department of Transportation and Development
   P.O. Box 94245
   Baton Rouge, LA 70804-9245

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13. Abstract

The purpose of this project was to develop a method that could be used to assess the costs and benefits of collecting and maintaining a database on any asset of DOTD, to aid in determining for which assets it was worthwhile to collect data. The literature review established that a methodology for doing this does not already exist. The literature review also helped to define what are the costs involved in collecting data and what benefits might accrue from establishing a database on various assets.

Initially, three modules were defined to aid in developing the methodology – costs for establishing a database, costs for maintaining the database, and benefits to be gained from having a database. The costs and benefits were assessed independent of whether the existence of a database would result in applying asset management procedures to the asset. Within each module, factors affecting the module were documented. These factors were used to generate questions about an asset that would allow determination of the costs or benefits. These questions were then incorporated into an Excel workbook with three questionnaires. These questions addressed the characteristics needed to describe the asset, an assessment of the data available or required on the asset, and the benefits of having data on the asset. The responses to the questionnaires are summarized on a fourth spreadsheet that scores the answers and provides an assessment of the costs and benefits on a five-point scale from "Very Low" to "Very High."

Tests were conducted on the workbook with four asset classes—impact attenuators, guardrails, retaining walls, and culverts and cross drains. The results of these four assessments are provided in the report. They show the flexibility of the procedure especially to unknowns concerning an asset. It was noted that some assets are very heterogeneous and may benefit from being divided into subclasses and the workbook completed for each separate subclass.

Project Review Committee

Each research project will have an advisory committee appointed by the LTRC Director. The Project Review Committee is responsible for assisting the LTRC Administrator or Manager in the development of acceptable research problem statements, requests for proposals, review of research proposals, oversight of approved research projects, and implementation of findings.

LTRC appreciates the dedication of the following Project Review Committee Members in guiding this research study to fruition.

LTRC Administrator/Manager
Julius Codjoe
Special Studies Research Administrator

PRC Members
Vince Latino
Shane Caldwell
Kevin Reed
David Coarsey
David Miller

Directorate Implementation Sponsor
Christopher P. Knotts, P.E.
DOTD Chief Engineer

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By

Peter R. Stopher, Ph.D.
Ruijie "Rebecca" Bian, Ph.D.

Department of Civil and Environmental Engineering
Louisiana State University
Baton Rouge, LA 70803

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Implementation Statement

As Louisiana moves to follow federal guidelines with respect to maintaining, repairing, and replacing assets based on asset management principles, this methodology can be used to assist in selecting which assets have the highest priority for inclusion in an asset management framework. Clearly, there are some assets for which the costs of collecting and maintaining data would far exceed the benefits to be gained from having data on the asset; however, other assets would have the reverse situation of benefits far outweighing the costs of data collection. The methodology presented here provides an unbiased method for assessing the costs and benefits and allows different assets to be assessed on an equal footing.

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Introduction

State departments of transportation (DOTs) previously prepared Transportation Asset Management Plans (TAMP), as directed by the Federal Highway Administration (FHWA), which covers the National Highway System and the bridges on that system. Major elements of the data collection for these asset management plans are the Highway Performance Monitoring System (HPMS) and the National Bridge Inventory (NBI) file. The use of asset management plans for the highway system was first promulgated by MAP-21, which changed the emphasis from "Worst first" to "Preservation first" as the underlying rationale for allocating scarce resources to the nation's transportation systems. As stated in the 23 Code of Federal Regulation (CFR) Part 515.5, "*Asset management* means a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the life cycle of the assets at minimum practicable cost."

However, recent discussions in the transportation profession have recommended extending the principle of asset management planning to most or all the assets of each state that are used to provide transportation. These assets could include: intelligent transportation systems hardware and software; traffic signals; buildings such as those used for administration and operation of the state transportation system; walking trails; culverts; roadway lighting; signage; etc. In this instance, only roadside assets are being considered.

Asset management plans require data to support them. These data include a systematic inventory of the assets themselves, their current condition, risks associated with the future of these assets, and the level of use made of the assets. Such data collection would need to be undertaken on a daily basis, to provide a means to update the database and make it useful. Such data collection and analysis incurs significant costs, and may require a dedicated staff to maintain the data and use the analysis. This research is to identify the costs of such data collection, analysis, and planning as well as the benefits to the state of collecting and analyzing the data.

Louisiana, like most states and other countries, recently embraced the basic precepts of asset management planning as a replacement for previous methods of determining how and where to spend scarce funds for the repair and rehabilitation of the transportation infrastructure in the state (DOTD, 2019). While this change in approach provides a much more cost-efficient way of spending scarce transportation dollars, it is still largely supported for road and bridge preservation by the HPMS and NBI data that are routinely collected by the state. However, the literature on asset management, in addition to recent discussions at national conferences and elsewhere, suggests that this same approach should be extended to other assets of state DOTs. Arguably, one could suggest that this approach should be extended to all physical assets of the DOT. However, it could be argued that such an extension could be too expensive to be worthwhile, and that asset management should concentrate on the major assets of roads and bridges only. In this project, it is intended to look only at roadside assets since many of the other assets are already the subject of data collection and review.

It was the purpose of this research to develop a methodology that will allow DOTD to estimate the costs and benefits of collecting asset data for other roadside assets that are not currently included. The methodology should address the initial costs of establishing a database on an asset; estimate the costs of maintaining the dataset into the future; and estimate the benefits of collecting the data. This methodology should be sufficiently general that it can be applied to any assets that the DOTD may consider in the future. Furthermore, the costs and benefits were to be described only in terms of low, medium, or high, and determined in such a way as to allow staff of DOTD to come to a decision as to whether the costs and benefits of collecting and maintaining the data on a specific asset were worthwhile. The methodology is not intended to provide a specific dollar figure for any of the costs and benefits.

Literature Review

Introduction

The purpose of the literature review was to find out what information might already exist as to the costs and benefits of undertaking asset management for non-road, non-bridge, but road-related assets. Alternatively, it would be desirable to determine if there exists a methodology for estimating the costs and benefits of such asset management procedures. DOTD has also specified that it is primarily interested currently in undertaking asset management for cross drains, guard rails, crash attenuators, and pavement striping. Therefore, any information in the literature pertaining to these specific items is of particular interest in this review. In reviewing the literature, several insights can be gained on the benefits of applying asset management principals to different assets. In addition, there is a National Cooperative Highway Research Program (NCHRP) report that outlines a method for determining the return on investment in asset management procedures (NCHRP 866, 2018). These materials are discussed in this literature review. While application of the NCHRP methodology is not the goal of this research, the review of the procedure and the other literature provided a strong basis of knowledge about asset management data collection that has been helpful in developing the methodology that is the primary purpose of this research.

Fundamentals of Asset Management

Setting Targets

An initial requirement for applying asset management procedures and for evaluating the costs and benefits is to set a target that the asset management procedures are intended to achieve. This target is usually specified as a percentage of the asset that is to be in a state of good repair (SOGR) (CTDOT, 2019; Caltrans, 2015; Lew, 2017). Alternatively, it may be specified in the reverse as the maximum percentage to be in poor condition (MnDOT, 2019). Either way, there appears to be an absolute requirement to begin the process of evaluating the benefits and costs of asset management by setting the target. This makes good sense because without a target it is not possible to quantify the benefits of undertaking an asset management procedure.

Life-Cycle Planning

A second fundamental of asset management is life-cycle planning (Lew, 2017). What this means is that a major component of the benefits of asset management procedures is to reduce the life-cycle costs of an asset. The process of waiting until an asset fails before expending funds on replacement is the usual alternative to asset management. In asset management, it is assumed that routine maintenance is undertaken from time to time to extend the life of the asset and to reduce effectively the life-cycle cost (CTDOT, 2019; MnDOT, 2019; ODOT, 2019; *inter alia*). This means that it is necessary to determine the costs of rehabilitation and replacement under the strategy of reactive maintenance, compared to the costs of undertaking routine maintenance to extend the life of the asset. This is compared to the family car. The former strategy involves doing no repairs or maintenance to the vehicle until it will no longer run, in which time major repairs or total replacement is needed; whereas, the asset management approach is to routinely service the vehicle every so many thousand miles and keep the car, the asset, in good condition for as long as possible.

Risk Management

The third fundamental of asset management involves undertaking risk management concerning the need for expenditure on an asset. There are generally two primary categories of risk that are assessed and used in asset management (Caltrans, 2018; CTDOT, 2019; ODOT, 2019; UDOT, 2019; *inter alia*). The first has to do with risks relating to the finances available for undertaking routine maintenance, while the second relates to events that may impact the usability of an asset. The former are generally issues of federal and state funding availability and the risks that anticipated funds do not materialize, while the latter has more to do with catastrophic events that damage or destroy an asset. These may be events such as earthquakes, hurricanes, tornadoes, floods, other weather or natural phenomena-related events, or major crashes.

Review of State Transportation Asset Management Plans

All 50 states, Puerto Rico, and the District of Columbia have submitted Transportation Asset Management Plans (TAMP) within the past two or three years. All these plans have been reviewed. Most states include only pavements and bridges in their asset management plans. Culverts that are wider than 20 feet or greater than 20 feet in diameter are considered as bridges in most states and are included in their TAMPs under the general category of bridges. Smaller culverts are rarely included in the plans. Table 1 gives a list of non-road and non-bridge assets that are included in state TAMPs (other than Louisiana), indicating which states have included them in their most recent TAMPs.

The potential usefulness of this list is to determine if the plans of these states provide any indications of the costs and benefits of including these assets in their TAMPs. In particular, the starred items in Table 1 have been identified as being of special interest to DOTD, so any information on these specific assets may be of direct benefit to this project. As can be seen from Table 1, culverts and conduits have been included in four of the existing TAMPs, with traffic signals and signs being the next most common asset to be included.

Table 1. Non-Road and Non-Bridge Assets Included in Current TAMPs

Non-Road, Non-Bridge Asset	States Including These in TAMP
Advanced Traffic Management System (ATMS) devices	Utah
Conduit (including culverts and storm drains) *	Ohio
Drainage Culvert*	California, Massachusetts, Minnesota
High-Mast Light Towers	Minnesota
Highway Buildings	Connecticut, Minnesota
Intelligent Transportation Systems (ITS)	Minnesota, Nevada
Lighting	Minnesota
Noise Walls	Minnesota
Pavement Markings*	Connecticut
Pedestrian Infrastructure	Minnesota
Signs	Connecticut, Minnesota
Sign Supports	Connecticut
TMS (Transportation Management Systems)	California
Traffic Signals	Connecticut, Minnesota, Utah
Tunnels	District of Columbia, Minnesota

* These items are of specific interest to the DOTD

In accordance with the goals of this project, the literature review ignores asset management planning for roads and bridges, and concentrates on the non-road and non-bridge but road-related assets, especially those that have been identified already by DOTD as being of specific interest in this project.

Culverts and Conduits (Cross Drains)

This is one of the four assets of particular interest to DOTD. Table 1 shows that four states – California, Massachusetts, Minnesota, and Ohio – included discussion of these in their TAMPs.

Target

These four states have adopted significantly different strategies with respect to culverts. California DOT (Caltrans) rates culverts as 0 when new; 1 as good condition; 2 as fair condition; 3 as poor condition; and 4 as failed (Caltrans, 2018). Their target is to have 100 percent of culverts in fair or better condition. Massachusetts DOT (MassDOT) rates their culverts on the same scale that is used for bridges with 7 through 9 as good to excellent condition; 5 through 6 as fair condition; and 0 through 4 as poor. No targets are specified, however, and there is little additional information in the TAMP about culverts (MassDOT, 2019). Minnesota DOT (MnDOT) has the most comprehensive data on culverts (MnDOT, 2019). Minnesota measures the condition of culverts on a 5-point scale with 1 being good condition; 2 is fair condition; 3 to 4 is poor condition; and 0 indicates not able to be observed. Their target is to have less than 10 percent of all culverts in poor condition. Ohio DOT (ODOT) rates its conduits on a 10-point scale, where 9 is excellent condition; 5 through 8 is fair or better; 1 through 4 is poor; and 0 is a total fail (ODOT, 2019). ODOT uses a Critical Success Factor for conduits (ODOT, 2019). The factor is set at 5 as the goal, which means all conduits should be rated as 5 or better (ODOT, 2019).

Inventory

None of the states considering culverts have undertaken and continue to undertake an ongoing 100% inventory per year. Caltrans reported that they have inventoried 110,000 drainage assets totaling 10.65 million linear feet. They are continuing to inventory and inspect drainage assets, and are completing between 8,000 and 12,000 per year with expectation of completing their inventory in 2027 (Caltrans, 2018). MassDOT performs culvert inspections in advance of pavement resurfacing projects and has also developed a strategy using geomorphology to identify and prioritize existing culverts that are vulnerable to storm damage (MassDOT, 2019). MnDOT collects data on culverts with a frequency of between one and six years, depending on condition (MnDOT, 2019). Culverts in condition 1 or 2 are inspected every six years, while those in condition 3 or 4 are inspected every one to two years. ODOT had an inventory undertaken by contract in 2017, which covered 88,000 conduits (ODOT, 2019). Ongoing inspections are conducted at varying frequencies from one to ten years, depending on size and condition of the conduit.

Deterioration Modeling

Ideally, each asset would have a model of deterioration, which would allow prediction of the changing condition over time. Only one of the states has such a model at this time. Some states indicate that they hope to develop such a model in the near future. In the meantime, the most common approach is to base forecasts of condition primarily on the age of the asset, and, to a lesser extent, on when any treatment has been undertaken.

Caltrans is the one state that has a model of deterioration. The model includes deterioration rates, treatments, and unit costs for drainage assets. The model assumes that the life of a culvert is approximately 50 years. Caltrans inspections show that, after 50 years of service life approximately 12 percent of culverts are in poor condition and 24 percent are in fair condition. This is also based on the assumption that maintenance will be undertaken every five years of the life of the culvert, with rehabilitation (invert paving or plating) taking place after 30 years of service at an average cost of $124,000. Caltrans has also determined that the costs to improve condition from fair to good are approximately $558 per linear foot, while improving from poor to good would cost $2,000 per linear foot, which is also the cost of building a new culvert. On average, five yearly maintenance costs are $400 per culvert. The report does not specify what maintenance involves. Average cost to construct a new culvert is estimated to be $180,000 if new road construction is not required. Average cost increases to $1,000,000 if construction involves both the road and culvert.

The other three states rely on the inventory to identify those culverts that are in need of replacement, and then put in place a life-cycle planning approach, as discussed in the next subsection of this review.

Life-Cycle Planning

Caltrans examined three possible scenarios for culverts. The first scenario involved cleaning out clogged culverts and replacing failed culverts. This scenario would maintain current condition and would not achieve the target of having culverts in at least fair condition. The cost of this strategy was estimated at $2.1 billion. The second scenario was an aggressive scenario involving fixing all fair condition culverts and bringing them up to good condition, and replacing all poor condition culverts and bringing them to good condition. This scenario was focused on reconstruction. It would bring 90 percent of the state's culverts to good condition in 10 years and would cost $6.3 billion. The third scenario was called a balanced approach and considered a mix of preservation and rehabilitation work. The scenario included ongoing maintenance on all culverts to preserve them over their expected life span. This scenario was estimated to cost $5.0 billion. It was the strategy adopted in the TAMP.

MassDOT also looked at life-cycle planning through two scenarios that were equivalent to the second and third scenarios of Caltrans. Their first scenario focused on a "worst-first" approach which involves replacing failed culverts and allocating all funds to rehabilitation and replacement costs. The second scenario was a balanced scenario that works toward an optimum mix of maintenance, preservation, rehabilitation, and reconstruction. This strategy is not only likely to result in lower overall costs but in a more reliable system as well. This was also the scenario adopted by MassDOT for the TAMP. The approach involves a mix of preservation and preventive maintenance (which includes both cyclical and condition-based maintenance), rehabilitation, and reconstruction.

MnDOT states, at the beginning of the chapter on life-cycle planning:

> "Although it is attractive to delay incurring preventive maintenance costs as much as possible in order to take advantage of the discount rate, doing so will typically only result in increased costs over time. When maintenance is delayed, the condition of each asset worsens, eventually affecting the serviceability or even the safety of the infrastructure. Also, certain kinds of preventive maintenance actions are highly cost-effective, but only if performed at the optimal time. For example, painting a steel bridge at the right time is highly effective in prolonging its life. However, if painting is delayed, too much of the steel may already be rusted and painting is no longer as effective (or even possible). A much more expensive

rehabilitation or replacement action is then required." (MnDOT, 2019, pp. 100-101)

For culverts, two strategies were considered – routine maintenance and the addition of three corrective actions. Culverts are inspected every six years when new, and more frequently for older culverts, depending on condition. Routine maintenance includes some condition-based repairs. Table 6-16 in the report (MnDOT, 2019), reproduced here as Table 2, summarizes the two scenarios for investment.

Table 2. Highway Culverts Life Cycle Planning Scenarios

ACTIVITY	TREATMENT WORK TYPE	TYPICAL COSTS	STRATEGY A MINIMUM MAINTENANCE	STRATEGY B CURRENT PRACTICE
Inspection	Routine Maintenance	$70	Applied	Applied
Cleaning	Routine Maintenance	$380	Applied	Applied
Reset Ends	Routine Maintenance	$3,000	Applied	Applied
Joint Repair	Corrective Actions	$3,300	Not Applied	Applied
Pave Invert	Corrective Actions	$1,980	Not Applied	Applied
Replace Ends	Corrective Actions	$5,800	Not Applied	Applied
Slip-liner	Rehabilitation or Replacement	$12,000	Applied	Applied
Cured In-place Liner	Rehabilitation or Replacement	$25,000	Applied	Applied
Trench Replacement	Rehabilitation or Replacement	$38,000	Applied	Applied
Jack Replacement	Rehabilitation or Replacement	$71,000	Applied	Applied
MnDOT EUAC PER CULVERT	N/A	N/A	$507	$356

(EUAC = Equivalent Uniform Annual Cost)

From this analysis, it was concluded that Strategy B – Current Practice – reduced the cost per culvert from $507 to $356 and would be the better strategy (MnDOT, 2019).

ODOT's conduit life-cycle planning analysis used a spreadsheet tool to analyze the benefits associated with different treatment strategies for a representative conduit. The spreadsheet tool used the result of conduit inspections to determine current conditions and a probabilistic analysis was conducted to forecast future conditions. Different levels of investment were considered, representing different types of treatments to address forecasted deterioration.

The following types of routine maintenance and corrective actions were considered in the analysis:

- Routine maintenance (cyclic)—cleaning
- Routine maintenance (reactive)—repairs
- Corrective actions—joint sealing/internal band sealing, paved invert, spray-on lining, slip lining, pipe bursting, pipe jacking
- Replacement—open-cut replacement

For small (12-36 inch) conduits, the preservation strategy improves conduit conditions over an alternative strategy that uses only rehabilitation and reconstruction. In this example, the use of planned preservation treatments while the conduit is still in relatively good condition added approximately 25 years to the life of a conduit. Similar results were generated for other conduit sizes, illustrating the long-term benefits associated with conduit preservation investments. Table 3 illustrates the types of treatments ODOT may consider in each of the work type categories included in their investment strategies.

As seen in the case of culverts or conduits, the four states are in general agreement on a balanced approach that involves undertaking maintenance of all culverts or conduits, with rehabilitation and reconstruction only on a limited basis.

Table 3. Conduit Treatments Available

FHWA Work Type Category	Conduit Treatment Types
Routine Maintenance	Conduit cleaning
	Minor repairs
Preservation	Joint sealing
	Internal band sealing
Rehabilitation	Paved invert
	Spray-on lining
	Slip lining
	Pipe bursting
	Pipe jacking

FHWA Work Type Category	Conduit Treatment Types
Reconstruction	Open-cut replacement
Initial Construction	New Conduit

Risk Management

The final aspect of asset management planning is that of risk management. FHWA defines risk management as, “the processes and framework for managing potential risks, including identifying, analyzing, evaluating, and addressing the risks to assets and system performance” (FHWA, 2017). This includes day-to-day concerns such as risks that assets will deteriorate faster than expected; projects will cost more than budgeted; or the potentially catastrophic risks of asset failure caused by factors such as natural disasters. Climate change also presents a looming risk that will exacerbate all weather-related risks.

Caltrans (2018) has defined seven basic categories of risks that may impact the TAMP. These categories are:

- Asset performance
- Highway safety
- External threats
- Finances
- Information and decision making
- Business operations
- Program and project management

Caltrans (2018) states that considering risk is important in developing a TAMP for the simple reason that transportation agencies often must spend significant resources responding to and/or mitigating risks. Reacting to the uncertainty presented by risks can be more expensive than proactive management. Risk management strengthens asset management by explicitly recognizing that any objective faces uncertainty. Being proactive rather than reactive in managing risk, and avoiding “management by crisis” helps the state to best use available resources to minimize and respond to risk, as well as to further build public trust.

Included in the strategies for mitigating risk are:

- Regular documented inspection programs
- Documented allocation of funding for repair and maintenance
- Documentation of competing resource demands
- Determined intervention levels
- Prioritized actions and documented reasoning

Caltrans developed a Transportation Asset Management (TAM) risk register by performing an initial assessment of the risks identified through enterprise risk management efforts. A risk register is a simple spreadsheet or matrix that summarizes an organization's risks, how they are analyzed, and records how they will be managed. The Caltrans TAM risk register uses a simple table format to capture risks, illustrate their estimated likelihood and impact, and record risk mitigation strategies and actions.

Enterprise risks affect the mission, vision, and overall results of MassDOT's asset management efforts (MassDOT, 2019). The section summarizes the following high-priority enterprise risks actively being addressed by the department. In many cases, these risks are pursued at the direction of MassDOT leadership with the support of the Transportation Board:

- Communication and transparency
- Coastal vulnerability
- Stream and river crossing vulnerability

Culverts on many high-volume corridors date back to original construction. The age of the infrastructure, along with increased duration and intensity of storm events, increase the likelihood of a culvert failure which has the potential of limiting mobility on high-priority corridors. Strategies to mitigate these risks include:

- Construction coordination and management planning
- Information technology—Disaster Recovery Plan

MnDOT (2019) identifies several risks to the transportation system and the TAMP. Among these are:

- Natural events (e.g., floods, storms, earth movement)

- Operational hazards (e.g., vehicle and vessel collisions, failure or inadequacy of safety features, construction incidents)
- Asset aging effects (e.g., steel fatigue or corrosion, advanced deterioration due to insufficient preservation or maintenance)
- Adverse conditions in the economy (e.g., shortage of labor or materials, recession)
- Staff errors or omissions in facility design, operations, or provision of services; or defective materials or equipment
- Lack of up-to-date information about defects or deterioration, or insufficient understanding of deterioration processes and cost drivers

Even for factors that are difficult to measure, though, it is possible to adopt general risk management strategies, such as:

- Having an inventory of assets MnDOT owns and maintains
- Conducting routine inspections to understand the condition of MnDOT's assets
- Raising awareness of risks among staff and the public
- Adopting management strategies and techniques to avoid risks
- Prioritizing risk-prone assets for replacement
- Using performance measures to mitigate and manage asset risks
- Working with partners and stakeholders on ways to reduce or to jointly manage risks through maintenance agreements, jurisdictional transfer, or other management strategies (MnDOT, 2019)

MnDOT has then assigned responsibility for managing and mitigating risks to appropriate levels within the organization.

ODOT has considered risks in managing its transportation network for years, following the risk management framework originally developed by the Institute of Organizational Standards (ISO). This framework involves the following five steps:

- Establish the context—identify what risks will be considered and how they will be evaluated.

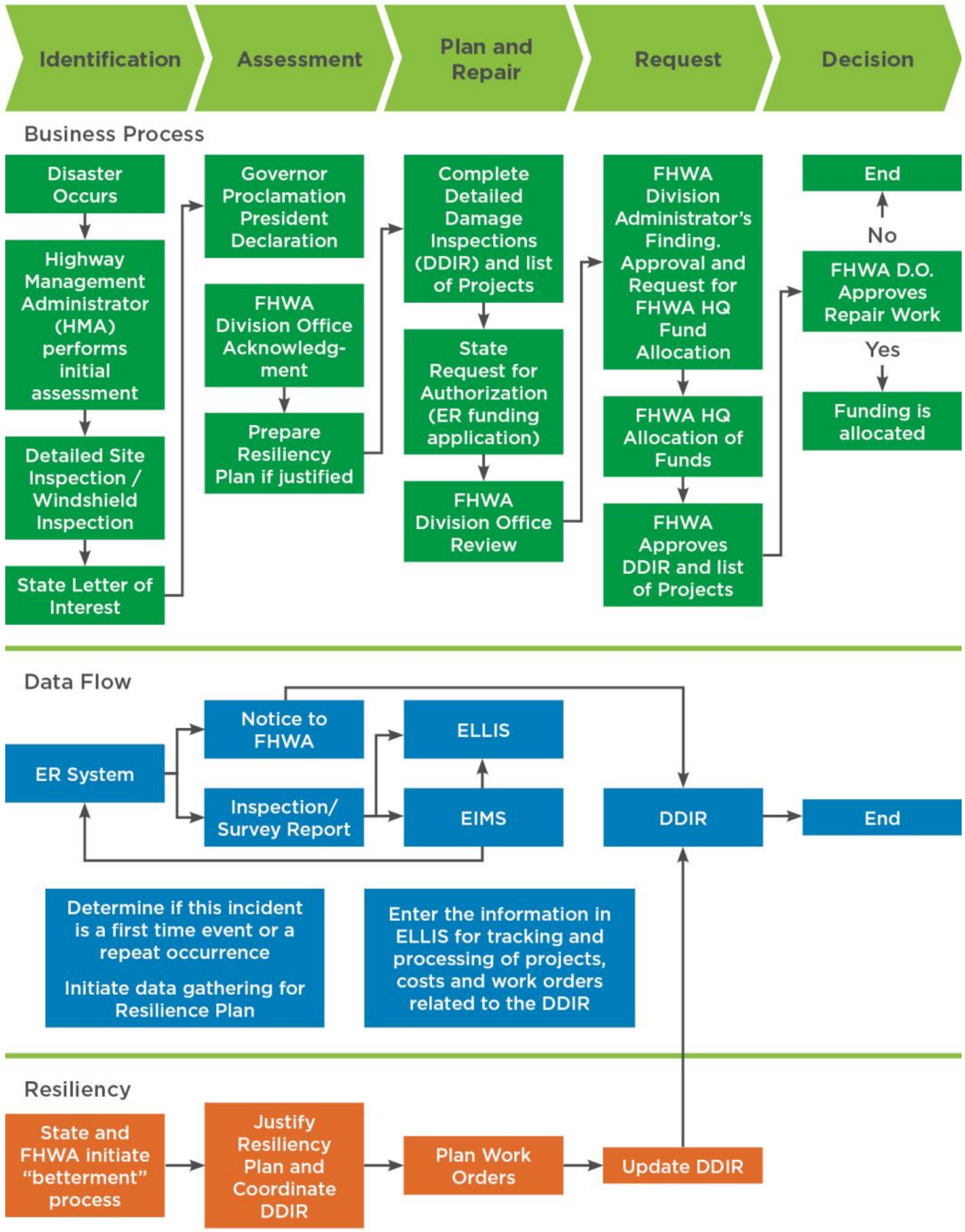
- Identify risks—identify the risks that could hinder ODOT’s ability to achieve its Asset Management objectives.
- Analyze risks—use agency-established metrics to evaluate the likelihood and impact of each risk.
- Evaluate risks—prioritize the results of the analysis.
- Treat risks—identify a plan for mitigating the top priority risks (ODOT, 2019).

The risk analysis conducted for the TAMP considered a variety of different types of risks related to the following:

- Flat funding and inflation, impacting ODOT’s ability to continue meeting Critical Success Factors while costs climb and the department’s buying power decreases.
- The availability of data, models, and tools (e.g., management systems) to predict and evaluate asset conditions over time so dollars are invested wisely.
- Asset vulnerability due to extraordinary weather events such as catastrophic flooding, high winds, and hot/cold extremes.
- Increases in truck freight that adds to congestion in areas not designed to handle the traffic volume and causes more rapid wear and tear on pavements and bridges.
- Asset-related risks that hinder ODOT’s ability to manage its assets effectively, such as the uncertainty that Conduit inspections will be completed on a timely basis.
- Potential workforce changes through retirements that could impact ODOT’s ability to implement its investment strategies unless institutional knowledge is preserved.
- Leadership and organizational changes that could impact existing goals and priorities.

A summary of the business processes, data sources, and resiliency plans to address assets that have been damaged due to repeat events is provided and illustrated in Figure 1.

Figure 1. ODOT risk procedure



Pavement Striping

Only one state, Connecticut, included pavement striping in their TAMP (CTDOT, 2019). Pavement stripings are of two types—lines and symbols. The unit of measurement of lines is linear feet, while that of symbols is square feet. Pavement stripings in Connecticut use one of three methods for applying stripings—use of water-based markings, epoxy, and in-laid epoxy.

Targets

A common performance measure is used for all assets, being the percentage of the asset that is in a state of good repair (SOGR). Initially, the TAMP reports on the expected performance levels of each asset with a two-year and a four-year horizon. Following this, the targets are established for each asset for a 10-year planning horizon. The 10-year performance goals for pavement markings of both types are 75 percent in a SOGR.

For pavement striping, Connecticut DOT (CTDOT) currently replaces about 13 million linear feet of line markings and about 350,000 square feet of symbols annually. Currently, only about 28 percent of line markings are in a SOGR. With no funding, this would drop to 0 percent in three years, while current funding levels would raise the SOGR to about 38 percent. Preferred funding would reach the target SOGR in about six years and would then maintain it. Pavement symbols are at about 55 percent SOGR. Zero funding would see this deteriorate to zero percent SOGR in four years. Maintaining the current budget would see the SOGR rise to about 64 percent in four years and would then maintain this level thereafter—11 percent below target. The preferred budget would bring the SOGR to 80 percent in three years and then maintain this level—5 percent above target.

Pavement striping is divided into two categories – line striping, and symbols and legends painted on the road surface (e.g., arrows, crosswalks, etc.). Only two ratings are used for pavement striping. These are again defined based on age. In-laid epoxy markings installed within six years are in good condition. Epoxy pavement markings installed in the past three years are also rated good, while water-based pavement markings installed in the past year are considered good. All older markings are considered poor. The absence of a fair condition is based on the short life of this asset.

Inventory

CTDOT’s inventory of pavement striping is quite limited. Pavement striping data are based on age and type of marking only. Methods to improve this inventory are being explored by CTDOT.

Deterioration Modeling

Similar to the situation with conduits and culverts, there are currently no deterioration models of pavement striping. CTDOT uses age as the metric for determining condition. Water-based markings are assumed to have an expected life of one year. Epoxy markings have an expected life of three years, and in-laid epoxy markings have a life of six years.

Life-Cycle Planning for Pavement Markings

CTDOT's approach is an age-based approach, with water-based markings replaced after one year, epoxy after three years, and in-laid epoxy after six years. Replacement is the only treatment available. Currently, CTDOT does not have a cost for replacement of water-based markings. Table 4 shows the costs of replacement of the other markings.

Table 4. Replacement Costs for Pavement Markings

Treatment	Unit	Unit Cost
Line Striping Replacement (epoxy only)	Linear Feet	$0.50
Symbols and Legends replacement (epoxy only)	Square Feet	$3.50
In-laid Line Striping Replacement (groove and epoxy only)	Linear Feet	$1.15

CTDOT's lifecycle approach to pavement striping is to replace pavement striping at the end of its expected life. The lifecycle strategies for pavement striping are shown in Table 5.

Table 5. Treatment Options for Pavement Striping

Management Method	Description
Condition-Based Replacement	Reduced retro-reflectivity or level of service triggers location-specific treatments
Age-Based Replacement	Replace pavement marking based on asset age with epoxy preferred

Risk Management

The CTDOT TAMP states:

> "Considering risk is important in developing a TAMP for the simple reason that reacting to risks is more expensive than proactive management. Employing risk management strengthens asset management programs by explicitly recognizing that any objective faces uncertainty and implementing mitigation strategies to reduce that uncertainty and its effects. Being proactive rather than reactive in managing risk will help CTDOT to better utilize capital funding toward maximizing the condition of all transportation assets." (CTDOT, 2019, p. 6-2)

The CTDOT TAMP identifies several risks that are common to all DOTs and to all assets. These are as follows:

- Insufficient state and federal funding
- Insufficient and/or inexperienced staffing
- Construction inflation costs
- Inability to meet two-year and four-year targets and adhere to the TAMP financial plan due to project delay and budget constraints
- Extreme weather or climate events
- Support for asset management implementation throughout the agency
- Changing agency priorities due to political pressures
- Availability and quality of data, information, and reliable models to allow the accurate projection of future conditions (CTDOT, 2019)

For each asset in the TAMP, CTDOT developed a risk register, which is a table or matrix format "…that is used as a risk management tool to summarize an organization's risks, analyze the likelihood and impact, and record possible risk-response strategies" (CTDOT, 2019, p.6-6). Table 6 shows an illustration of the assessment of risks for pavement striping (extracted from Table 6-1 in CTDOT, 2019).

There is a second part of the risk management process, which has to do with emergency situations, such as catastrophic failures or weather-related emergencies. An emergency situation is defined as, "…a natural disaster or catastrophic failure resulting in an emergency declared by the Governor of the State, or an emergency or disaster declared by the President of the United States" (*Code of Federal Regulations*, 2016). CTDOT is still developing this aspect of risk assessment.

Table 6. Risk Statements and Mitigation Strategies for Pavement Markings (CTDOT, 2019)

Asset	Risk Statement	Risk Rating	Mitigation Strategies	Mitigation Status
Pavement Marking	If there is insufficient staffing due to sign priorities, VIP paving, complaints, and available staff skill sets, then less work will get done and safety will be impacted.	Very High	• Address staffing issues • Address critical need for specially trained operators	• In Progress/Deployed • In Progress/ Deployed
Pavement Marking	If funding decreases or is uncertain, then less work will get done and safety will be impacted	Very High	• Take steps to ensure necessary funding	• In Discussion
Pavement Marking	If weather conditions are not favorable for paint application (cold/rain), then less work will get done and safety will be impacted	High	• Adopt strategies to account for variability in weather	• Implemented / Ongoing
Pavement Marking	If equipment is not functioning properly and up-to-date for application needs (example painting of rumble strips, etc.), then work cannot be achieved, and safety will be impacted	High	• Develop plan to address critical equipment redundancy needs	• Implemented / Ongoing
Pavement Marking	If there is insufficient MPT (Maintenance and Protection of Traffic) staff and equipment, then work cannot be achieved, and safety will be impacted	High	• Improve coordination between Signs & Markings and MPT crew schedules; availability of cone trucks for sign and marking operations	• Implemented / Ongoing

Summary of State TAMPs

In summary, these are the only examples of asset management planning to be found in the current TAMPs of the states. There are no cases in which crash barriers and impact attenuators are included in a state TAMP. However, the general approaches shown in relation to conduits and pavement markings are applicable to crash barriers and impact attenuators, and any other assets that should be considered in the future. Reviewing the strategies adopted for other non-road, non-bridge assets by state DOTs, the same approaches have been taken with other assets as those described here relating to conduits and pavement markings. It is generally common that these other assets do not currently have deterioration models available and that the most common strategy is to assume that deterioration is age and material related, except when complaints or unexpected incidents occur that cause damage to the assets.

The most common benefit that is discussed in relation to these assets is the maintenance of the value of the investments. Most of the states report on their efforts to estimate the asset value of each asset that is managed (e.g., Caltrans, 2018; MnDOT, 2019; ODOT, 2019). Estimating the asset value can then help in making the case for asset management, where it can be shown that the loss of asset value if a "worst first" strategy is applied is much greater than the costs of applying asset management.

Determination of the Costs and Benefits of Asset Management

Apart from the documentation of how asset management is applied to various non-road, non-bridge assets, as discussed in the previous sections of this report, there is a need to determine how to measure the costs and benefits of applying asset management procedures to various assets. Several papers discuss these issues.

Principal among the benefits that are discussed are:

- Better knowledge of the state of the transportation assets throughout a state (Lew, 2017; Mizasawa and McNeil, 2005).
- Clear criteria for investment decisions that may appear to the public to be hard decisions, such as maintaining and preserving one facility while allowing another to fall into substantial disrepair (Lew, 2017; Mizasawa and McNeil, 2005).
- Common definitions and standards for maintenance and rehabilitation (Mizasawa and McNeil, 2005).
- Economic modeling (Mizasawa and McNeil, 2005).
    - provision of an estimate of the economic effect of spending scenarios (scenario analysis)
    - ability to manage assets on an economic basis (cost-benefit, engineering economics)
    - prioritization of maintenance needs based on future costs rather than current condition (life-cycle cost)
    - selection of the best maintenance and rehabilitation measures or strategies (Mizasawa and McNeil, 2005)
- Comprehensive, comparative assessment of:

  - current status of the network
  - expected future status (Mizasawa and McNeil, 2005)
- Objectively based answers to:
  - what level of funding is required to keep the current status
  - the implications of greater or lesser budgets
  - the implications of deferred work
  - the implications of lower standards (Mizasawa and McNeil, 2005)
- Satisfaction of providing best value for available funds (Mizasawa and McNeil, 2005).
- Capability of assessing the implications of less funds, lower standards (Mizasawa and McNeil, 2005).
- Capability of making the case for higher standards (Mizasawa and McNeil, 2005).
- Capability of quantifying the assessment of the condition (Mizasawa and McNeil, 2005).
- Improved credibility of decision-making process when dealing with top management (Mizasawa and McNeil, 2005).

Good data about the state's transportation assets is critical to the implementation of asset management planning. It is suggested that the acquisition of such data represents a clear benefit of asset management (Lew, 2017), especially where this allows decision makers to anticipate future needs of the assets in the state. Mizasawa and McNeil (2005) suggest that, among the benefits from asset inventories are:

- Ability to build more accurate information
- Ability to track the performance of treatment strategies
- Ability of a wide range of staff to query database
- Integrated harmonized database (consistent data)
- Provision of up-to-date accurate information on the condition

Several other benefits are also suggested by Mizasawa and McNeil (2005), who also document the costs of asset management as follows:

- Data collection, processing, storage, and analysis
- Software development/acquisition and installing the system
- Computer hardware, staff
- Operating costs of the system
- Making changes in procedures
- Extra time and effort to upgrade skills and learn new procedures
- Training and education costs

Mizasawa and McNeil (2005) also suggest that there are added user costs in the form of:

- Increase of user costs and environmental impacts due to:
    - — frequent preventive maintenance and rehabilitation works
    - — increase of driving speed
    - — inducing additional traffic produced by high quality roads

Mizasawa and McNeil (2005) start from the premise that justification for investing in the tools and procedures for asset management requires that the benefits of asset management must not only be estimated, but also need to be estimated in monetary terms, so that agencies can demonstrate the value of investing in asset management. Hence, the benefits and costs summarized in the preceding paragraphs all need to be estimated in monetary terms to determine the costs and benefits of applying asset management procedures.

Mizasawa and McNeil (2005) suggest three methods for quantifying the costs and benefits. The first is before-and-after analysis, which can be used only as a retrospective tool, i.e., when asset management was introduced in earlier years and there is a record of the effects of introducing asset management. This still requires simulation of the situation that would have existed if the asset management system had not been introduced. The second method is regression analysis. This can be used for both retrospective and prospective situations. In the case of retrospective, it will require simulation again of the situation in which asset management had not been introduced. In the case of prospective, both the situation with and without an asset management system will need to be simulated. The third method is benefit-cost analysis. This also requires the same simulations. Mizasawa and McNeil (2005) discuss all three methods with respect to pavement management but do not document any application of these methods to other assets.

NCHRP Report 866

This report (NCHRP, 2018) provides tools that could be used in Louisiana. It lays out a methodology for estimating the return on investment from adopting asset management practices for any asset of a state agency. A detailed summary and review of the report is provided in this section.

Introduction

This report is the final report for NCHRP project 20-100, "Return on Investment in Transportation Asset Management Systems and Practices." The report indicates first that it looks at three classes of asset—pavements, bridges, and maintenance. However, it is suggested that the method described in the report can be applied to other classes of asset.

Framework for Estimating Return on Investment

The method recommended involves putting together a base case and an investment case. The former is what would have been done, if the TAM was not put in place, while the latter is what is put in place with the TAM. Then costs and benefits need to be determined over a period of years, with discounting to the present, and a standard Benefit-Cost Analysis (BCA) undertaken.

The report identifies three groups that may benefit from an asset management program—the agency, the users of the asset, and the general public. It notes that the latter two are more involved and may be more difficult to estimate. The costs derive mainly from two sources—capital and operating. These make up the costs and benefits for use in a standard BCA. The potential benefits are shown in Table 7, reproduced here, and divided into the different recipients of the benefits.

Similarly, Table 8 shows the life-cycle costs of asset management programs. It is suggested that the number of years for which the costs and benefits should be estimated is in the range of 10 to 20 years. This means that renewal costs need to be taken into account in many instances.

The report then documents procedures for estimating the various costs and benefits and compares the methods for analyzing the return on investment, looking at Net Present Value, Benefit-Cost Ratios, Internal Rate of Return, and Payback Period.

Table 7. Potential Benefits of TAMP Investments by Stakeholder Group

Direct and Indirect Agency Cost Savings	User Cost Savings	Benefits to the General Public (Social Benefits)
1. Staff time savings from improved data collection and accessibility	1. Vehicle operating cost savings (e.g., reduced wear and tear, reduced fuel consumption) from smoother pavements or more direct routing (e.g., with enhanced bridge availability through improved maintenance and a reduction in postings)	1. Reduced emissions (e.g., from smoother pavements or more direct routing)
2. Cost savings from the optimization of investment strategies	2. Travel time savings (e.g., reduced work zone delays, reduced time spent on detours)	2. Reduced noise generation
3. Lower costs from reductions in failure risks for critical assets (e.g., bridges)	3. Savings from accelerated improvements to transportation system maintenance, rehabilitation, or capacity that reflect timely agency decisions regarding asset management	
4. Avoided outlays for legacy systems, including hardware maintenance and software updates	4. Safety benefits (e.g., briefer exposure to work zones, alternate/unfamiliar routes, temporary traffic pattern changes; overall improved safety of transportation infrastructure being used)	
5. Enhanced reputation and level of public trust gained through information sharing		
6. Delayed capital expenditures due to increased asset life (residual value of assets)		
7. Reduced worker safety costs (due to bundling of projects)		

Table 8. Life Cycle Costs of TAMP Investments

Non-Recurring Costs	Recurring Costs
1. Hardware and software acquisition	1. Maintenance and repair
2. Installation	2. Operating expenses
3. Training	3. Software maintenance costs
4. Decommissioning	4. Software updates
5. Shift in investments (e.g., delay in some investments to perform additional preservation or other	5. Data collection and data analysis cost

Before getting into these methods, several methods are suggested for estimating the costs and benefits, including simulations, controlled field experiments, time-series analyses, and breakeven analyses. In discussing simulation methods, it is noted that, “a criticism of simulation models is that the same decision criteria used by the TAM systems to select asset treatments are used to assess the performance of those treatments or tools relative to current practices” (NCHRP, 2018). In terms of controlled field experiments, these can only be conducted if part of the agency’s system uses TAM procedures and part does not; or when a comparison can be made between two neighboring agencies, where one is using TAM procedures and the other is not. Time-series analysis can be used when the agency has implemented the TAM procedures for some years (it is suggested at least 10 years). Instances of this were not found in their literature review. Breakeven analysis can be conducted when the benefits are not easily quantified. An example is provided in Appendix A of the NCHRP report.

The report then proceeds to discuss the need for discounting of future costs and benefits and recommends ways to determine the appropriate discount rate. After then discussing the four methods of assessing the return on investment, the report notes that there is uncertainty in the assessment of many of the future benefits and costs and suggests several methods by which the sensitivity to these uncertainties can be handled. Sensitivity analysis, quantitative risk analysis, scenario analysis, and what-if analysis are each discussed in turn. Recommendations for which method to use are not made at this point in the report.

Case Studies

This chapter documents three case studies and a pilot study. The three case studies involved a pavement management system (PMS) in a western state, a bridge management system (BMS) in an eastern state, and a maintenance management system (MMS) in a southern state. Each of these case studies was performed retrospectively, but the pilot study was a prospective one used to validate the Return on Investment (ROI) tool developed in the project.

The first case study is of the PMS of a western state. The following is noted about this state and its use of asset management:

> “An important change in policy that occurred following the implementation of the PMS was that, in 2002, the agency’s chief engineer required that regional engineers base at least 70% of their surface treatment projects on

recommendations from the PMS. This percentage was increased to 80% in 2012. Also, in 2003 the agency implemented a policy that regions needed to spend at least 5% of their capital funds on preventive maintenance treatments, whereas previously they had typically spent nearly all funds on more aggressive rehabilitation and reconstruction treatments. The net effect of these changes was that, beginning in 2003, pavement engineers began making much more significant use of the system to develop project recommendations, and over time a shift occurred to increased emphasis on lower cost, less aggressive treatments to the extent that these were recommended by the PMS." (NCHRP, 2018)

Table 9 is useful to give an idea of the cost components and how this is put together to assess the cost side of the asset management system. However, further details of this case study are not included in this summary and review, because this is not an area of interest to Louisiana, which is already using asset management for highways.

The second case study is of a bridge management system in an eastern state. The procedure for this case study is fairly similar to the previous one. However, some specific benefits are noted that arose from the adoption by this state of a TAM. Quoting from the NCHRP Report, these benefits are shown in Table 9.

Table 9. PMS Implementation Cost by Year

Year	Staff	Data Collection	Hardware & Software	Software Support	Consulting	Total	Total (2012 $)
1999	$408,415	$268,637	$454,800	$20,000	$170,000	$1,321,852	$2,461,157
2000	416,585	282,069	0	12,126	0	710,780	1,259,183
2001	424,919	296,172	0	13,725	0	734,816	1,238,596
2002	433,417	310,981	0	13,900	0	758,298	1,216,153
2003	442,087	326,530	0	13,900	0	782,517	1,194,096
2004	450,931	342,857	35,000	14,750	0	843,538	1,224,750
2005	459,951	360,000	0	15,500	0	835,451	1,154,147
2006	469,151	374,667	0	16,800	0	860,618	1,131,222
2007	478,533	389,334	0	20,800	0	888,667	1,111,409
2008	488,106	404,000	0	28,560	0	920,666	1,095,555
2009	431,603	420,000	0	31,260	0	882,863	999,592
2010	440,237	436,000	0	34,200	0	910,437	980,791
2011	449,043	452,000	180,793	0	76,450	1,158,286	1,187,243
2012	458,021	468,000	0	0	83,150	1,009,171	1,009,171
Total	**$6,250,999**	**$5,131,247**	**$670,593**	**$235,521**	**$329,600**	**$12,617,960**	**$17,263,065**

- "Increased inspection efficiency, accuracy, and consistency of the bridge inspection process;

- “Elimination of paperwork, which allowed inspectors to spend more time on inspections;
- “Immediate availability of inspection reports, which allowed analysts to view reports sooner and react faster to bridges that need repairs; and
- “Digital storage of reports, which allowed multiple people to view reports at the same time, improving quality control.” (NCHRP, 2018)

The third case study, and potentially the most interesting one for Louisiana, was not able to be completed because of lack of the needed data. It concerned a maintenance management system in a southern state. The maintenance budget was used to maintain roadway, roadside, drainage, bridge, and traffic service. In the mid-2000s, the state changed from a focus on tracking maintenance activities to one of measuring the level of service (LOS) of different roadway features. Details of the way in which the state assigned LOS grades to different features are not provided in the report, although an example is given of measuring roadway LOS by potholes per mile. To support this system, the state DOT collects data annually from 2,400 random sample inspections of roadways and rights of way. The LOS approach, which required rating asset conditions by district and road class from A to F, together with a new TAMP system would support the following tasks:

- “Tracking system condition and performance to develop needs-based estimates;
- “Prioritizing maintenance needs;
- “Providing an improved basis to support budget requests and allocate resources among activities and districts;
- “Showing the relationships between LOS and costs; and
- “Supporting communication and reporting.” (NCHRP, 2018)

The NCHRP team decided to apply a time-series approach to this case, because this is rarely documented in the literature. The analysis concerned the maintenance expenditures and LOS measures reported in the Annual Maintenance Summary of the DOT. The maintenance summary also includes LOS targets for each year. The NCHRP team ran multiple regressions between the deviation from the target LOS levels and the maintenance expenditures for each year from 2007 to 2014. While data were not available to allow estimation of the dollar value of the benefits, the regressions did show that the new TAM system had resulted in more cost-effective management of the maintenance of these assets.

ROI Calculation Guidance

The next chapter of the report documents guidance on calculating the ROI of TAM systems whether new, enhanced, improved, or upgraded. While investments in roadways and bridges benefit the users of the highway system directly, the benefits of a new or improved asset management system are a benefit to the agency by improving the efficiency of the agency. Secondary benefits may include the users of the highway system due to reduction in time spent in road closings or traffic reductions due to maintenance activities. It may also include benefits to non-users, such as improved air quality.

To estimate the ROI through a BCA involves estimating the costs over a period of time and also the benefits and then discounting these based on the time value of money. While costs will almost always be readily measurable in U.S. dollars, benefits may be more difficult. If benefits cannot be converted into dollar values, then a different method of analysis, such as breakdown analysis, may be required. It is also necessary to consider two cases—the world with the asset management procedure in place and the world without the asset management procedure. Costs and benefits of both must be estimated and the ROI is determined by looking at the differences between the two sets of estimates.

A figure in the report (Figure 4-1, NCHRP, 2018) shows that Total Costs are the sum of Agency Initial Costs, Recurring Costs, and User Costs. The Total Benefits are made up, similarly, of Agency Benefits (comprising staff time costs from improved data collection, cost savings from optimizing maintenance activities, and lower insurance costs from risk avoidance), User Benefits (which may include travel-time savings, operating cost savings from smoother pavements, and benefits of accelerated repair, and maintenance), and General Public Benefits (which may include reduced emissions and reduced noise). Applying the discount rates to the stream of benefits and costs allows calculation of the ROI. The report cautions that the extent of the benefits will depend on how much the agency has already adopted TAM practices. The more assets covered, the lower the benefits will be.

A seven-step procedure is then introduced and discussed. Because this may represent a possible methodology for DOTD, the steps are described in some detail in the following sections. The seven-step procedure comprises the following steps, which are described in detail in the following subsections:

1. Define study purpose
2. Identify likely impacts
3. Assess available data
4. Establish modeling framework
5. Collect necessary data
6. Conduct analysis
7. Estimate ROI and summarize results

Step 1 – Define Study Purpose

The study purpose impacts the rest of the process. Step 1 has two tasks. The first task is to define the focus of the study. The NCHRP team defined five criteria that should guide the definition of the study purpose:

- Does the study concern an existing TAM, or is it to justify a new investment? This determines whether the analysis will be prospective or retrospective.
- Is the primary audience for this analysis the agency, public officials, or the general public? If it is the agency, then an analysis of agency benefits may be sufficient. If it is public officials, then more effort needs to be made to assess user benefits. If it is the general public, then broader non-user benefits may need to be included.
- What resources are available? If these are limited, then a high-level analysis may be required.
- Has a similar analysis been conducted before? If so, the results of that analysis could be leveraged for this present study.
- Is the agency adopting TAM practices without implementing a TAM system? If TAM practices and systems are adopted in stages, carefully tracked changes to the agency’s costs and activities can be used to inform expectations for later improvements. (NCHRP, 2018)

The second task is to define the scope of the TAM investment. This would include considerations of:

- When and over what time period the investment is expected to take place
- What assets would be covered
- Whether or not this is an upgrade to an existing TAM system
- How long the investment will be in place before a major upgrade is likely to be needed

Among the inputs required would be:

- The percentage of assets covered
- The number of potential treatments included
- The functions incorporated into the TAM
- Other factors

A checklist is provided in Figure 19 of the report, which is reproduced here as Figure 2 (NCHRP, 2018).

Figure 2. TAM investment classification checklist

Goal of Analysis

- ❑ Justify TAM investment already made and in place
- ❑ Make the case for a new investment

Stated Purpose of Investment

- ❑ Better/more efficient use of agency resources
- ❑ Better management of asset condition or serviceable life
- ❑ Improved travel conditions
- ❑ Other

Step 2 – Identify Likely Impacts

This step results in preliminary identification of the likely impacts of implementing the TAM procedures or system. As noted earlier, these may encompass three main categories:

- The agency
- Users of the assets
- The general public

Agency impacts may include reductions in outlays and increases in staff productivity. There may also be a benefit of reduction of the asset management backlog. Estimation of this latter benefit is dealt with in Step 4. The NCHRP report also notes that there may be indirect benefits to the agency that should be considered, such as reduced data entry and processing times resulting from better organization of data and systems, and time savings for other staff because of better integration of asset data.

In some cases, there will also be benefits to users of the system, such as improved travel times, smoother pavements, reduction in accidents, and reduced delays for construction/maintenance. However, in most cases, the agency benefits will be sufficient to justify the investment, so the user benefits may not need to be estimated but can be included by reference and not monetized.

This step is intended to identify the likely impacts of adopting the TAM practice or system. It is suggested that there are at least three sources that can be used to identify these:

- Documentation and brochures of TAM software
- Interviews with agency personnel
- Experiences of other agencies as documented in the literature review

The intent of this step is to identify the impacts sufficiently to allow definition of the data needs and the relevance of potential impacts. There is a useful list of impacts provided in the report, reproduced here (NCHRP, 2018).

- Potential Impacts of TAM Investments
    - Transportation Agency
        - Reduced work backlog

        - Improved decision-making in allocating resources
        - Increased staff efficiency
        - Reduced expenditures (data collection, lower insurance costs, etc.)
        - Enhanced reputation and public trust through information sharing
        - Reduced chances of catastrophic failure
        - Improved data integration across offices/other systems[1]
    - Assets
        - Improved asset condition
        - Longer life expectancy
- Users and General Public
    - Improved travel efficiency
    - Reduced accidents
    - Fewer negative impacts (e.g., work zone delays)
    - Potential for increased economic activity along improved transportation assets (NCHRP, 2018)

It is suggested, at this point, that notes should be made about each impact as to whether it will be likely to impact the quality of the transportation asset or transportation system performance. Another possible impact would be reduction in staff needs, leading to cost savings at the agency.

Step 3: Assess Available Data

After reviewing the expected impacts from Step 2, this step involves assessing the data requirements for estimating those impacts. This step may also reveal data gaps that will need to be filled later in the process. It is also necessary to return to Step 1 and review the

[1] Among the impacts to the transportation agency, enhanced reputation and public trust, and reduced chances of catastrophic failure are unlikely to be quantifiable or able to be monetized.

goals of the analysis, to determine whether only agency benefits need to be estimated or if benefits to users and the general public are also required.

If prospective evaluation is the goal of the study, the two major requirements for the data will be:

- Data on current conditions of agency operations, transportation assets, and the performance of the transportation system. At a minimum, this will be agency expenditures for maintaining the assets and asset conditions. If a broader evaluation is to be done, then added to these will be transportation system performance and levels of use measures.
- Forecasts of the user benefits, agency costs, and transportation asset conditions under the two scenarios of business as usual and business with a TAM system in place.

If retrospective evaluation is the goal, then the data requirements will be:

- Observations of the conditions prior to implementing the TAM and after implementation
- Actual agency costs prior to and since TAM implementation
- Estimates of what conditions would have been if the TAM had not been implemented

The analysis cannot proceed without the initial and ongoing costs of the TAM investment. A list of potential costs is also included in the report and is reproduced here (NCHRP, 2018):

- Potential Costs of TAM Systems and Practices
    - Non-recurring Costs
        - Hardware and software purchase
        - Installation of hardware and software
        - Staff training for using TAM software
        - Decommissioning TAM system
    - Recurring Costs

- Operation, maintenance, and repair of transportation assets and user vehicles
- Maintenance and updates (renewals) of TAM software
- Software licensing fees
- Ongoing technical assistance
- Data collection and analysis (NCHRP, 2018)

There are also staff costs to be collected relating to the TAM system implementation. The report suggests a number of staff costs that should be included. It is further suggested that time costs for staff can be obtained from a number of different sources (NCHRP, 2018, page 50).

If it is necessary to estimate benefits to users and to the general public, and also to estimate the impacts on the quality of the agency's assets, then data will need to be collected on at least three elements of benefit:

- The condition of the assets
- The remaining life or asset condition
- The level of service provided by the assets

Depending on the function of the assets involved, data may also be needed on the levels of use of the assets, measures of performance of the assets, and the details of diversions and closures that might be required to deal with catastrophic failure of the assets. It is also noted that, if the evaluation is a retrospective one, then data may also be needed on weather conditions historically.

Finally, for this step, internal tools that can be used to simulate the effects of different investment scenarios will be needed. These tools will be used in a subsequent step to simulate what would have happened without the TAM system or procedures in place for a retrospective analysis, or to forecast scenarios with and without the TAM system or procedures in place for a prospective analysis.

Step 4: Establish Modeling Framework

As noted in the report, "Step 4 involves defining the investment case and base case, choosing the appropriate analytical method for quantifying impacts, and establishing key parameters" (NCHRP, 2018). The report divides this step into five tasks.

Task 1 involves the definition of the investment case. Seven questions are suggested as a basis for defining the investment case:

1. The percentage of the agency's assets that will be covered by the new TAM system or procedures
2. The percentage of agency needs that will be covered
3. The asset management approach to be used and how it differs from the present (or past) approach
4. The number of potential treatments that will be covered
5. The annual budget target for the assets
6. The percentage of the agency's budget that will be impacted by the new TAM system or procedures
7. The way in which agency operations will be changed over time

Task 2 involves the definition of the base case. The report cautions that the base case should be realistic. Again, there are questions that are suggested to establish the base case, and these address the following issues:

1. The ways in which the management of the asset(s) will change with the new TAM system or procedures
2. Data collection systems that would change with the new system or procedures
3. The way in which decision-making would change with the new system or procedures

Using the answers to these questions and the information assembled in steps 1 and 2, both the base case and the investment case can be defined. It is suggested that the base case be defined first and then the investment case can be defined by comparing the answers in task 1 to those in task 2.

Task 3 is to determine which benefits are needed to be included. The report notes: "The most commonly estimated benefits include staff time savings, reduced asset management backlog, and other agency cost savings. For many analyses, the residual value of improved assets can be one of the largest benefits, in part because of the comparatively long lifespan of transportation assets" (NCHRP, 2018). As has been noted previously, benefits to users and the general public may also be appropriate to include, depending on the purposes of the TAM system evaluation.

Task 4 is to choose the analytical method to quantify the impacts. The methods are described in chapter 2 of the report. Five methods are discussed in this section of the report. For prospective analysis (i.e., for a new TAM system or procedure that is intended to be introduced), simulation, benefit transfer, and expert assessment are the tools that could be suitable. For a retrospective analysis (i.e., to justify a TAM system or procedure that is already in place), simulation, benefit transfer, time series analysis, expert assessment, and field-controlled experiments are all potential methods that could be used.

Task 5 is to establish key parameters for the modeling. In this section of the report, these parameters are described. They include the timeframe for the analysis, the timing of the ramp-up in benefits (because benefits will not accrue immediately upon implementation), external factors that may impact the benefits (e.g., long term policy shifts, population demographic changes, etc.), economic variables (e.g., discount rate, inflation rate, and economic variables such as wage rates), and the level of sophistication of the TAM system or procedures.

Step 5: Collect Necessary Data

The report cautions that this may be the most time-consuming task of the analysis. Usually, it will require collecting existing data from a number of locations, rather than collecting original data in the field. Step 3 will have provided identification of the data required. Three strategies are also outlined in the report for providing key data items that may be missing. These include interpolation and extrapolation of existing limited data; the case studies, pilot testing, and literature available in the NCHRP Report 866; and examination of past policy changes and investments of the agency that could be considered as suitable proxies.

Step 6: Conduct Analysis

This is the step in which the analysis is undertaken, using the outputs of the previous tasks. It is noted that most agency benefits will be in the form of cost savings either from reductions in outlays or increases in productivity. It is also noted that the implementation of the TAM system or procedures may involve additional tasks, activities, and responsibilities, and these should be included as incremental costs, which will probably partly offset the benefits. Further, one of the largest benefits may be a decrease in the backlog of asset management. Estimating this will likely require the use of a simulation tool.

Once the agency benefits have been estimated, if needed, the wider benefits to users and the general public can be estimated. One of the possible tools for doing this is the ROI tool developed as part of NCHRP Project 20-100 (the project reported on in NCHRP Report 866) (NCHRP, 2018).

Step 7: Estimate Return on Investment and Summarize Results

This step consists of five tasks. The first task is to calculate the return-on-investment metrics, which is done through a series of seven calculations. These are summarized as follows:

1. Enter the direct costs and benefits for each year, convert to dollars, and adjust all values to a common year (base year).
2. Tabulate these values for the period of the analysis.
3. Calculate the present value (PV) of the costs and benefits by discounting future values, using the discount rate.
4. Subtract the base case PV from the investment case PV to determine the incremental benefits of the TAM system or procedures.
5. Perform calculation 4 for the costs, to determine the incremental costs of the TAM system or procedures.
6. Calculate the appropriate ROI metric, which could be the Net Present Value (NPV), the Benefit-Cost Ratio (B/C Ratio), the Internal Rate of Return (IRR), or the Payback Period.
7. Assess whether the BCA indicates that the TAM investment is justified.

The second task in this step is to account for benefits that cannot be monetized. A number of such benefits are listed in the report and are reproduced here as follows:

- “More efficient decision-making;

- “Increased service to the public;
- “Improved accountability and public trust;
- “Reduced failure risks for critical assets;
- “Longer life expectancy of assets;
- “Increased economic development along improved transportation assets;
- “Reduced congestion, lower noise levels, and fewer emissions from more efficient travel; and
- “Improved data quality.” (NCHRP, 2018)

Some of these benefits may be quantifiable, but not monetizable. It is also suggested that notes taken during the process that has led up to this point should be reviewed, particularly the expected benefits identified in Step 2 to ensure that all benefits have been considered.

Because of the complexity of the analysis of the costs and benefits of a TAM system or procedure, the third task is to undertake a preliminary review of the results of the analysis to check for unintended biases and errors. This should include reasonableness checks on the metrics produced this far. It is pointed out, for example, that a B/C Ratio of 300 is very unlikely to occur, whereas one of 3.5 is quite reasonable. Checks can also be made against the case studies in NCHRP Report 866 and other literature.

Task 4 involves accounting for the uncertainty in predictions. This will hold for both prospective and retrospective analyses. In the former, everything is based on forecasting to the future, while the latter involves forecasting what would have happened if the TAM investment had not been made. Therefore, it is suggested in this task that one of three possible methods be applied to account for the uncertainty and risk in these forecasts. If most benefits could not be quantified, it is recommended that a threshold or breakeven analysis be undertaken, details of which are provided in the NCHRP report on page 64 (NCHRP, 2018). If benefits are quantifiable, then a sensitivity or scenario analysis can be undertaken. Again, details of this method are provided on page 64 of the NCHRP report. Finally, on page 65 of the NCHRP report, a “what-if” analysis method is described that could also be applied (NCHRP, 2018).

The final task in this step is to present the findings. The way in which findings are presented will depend on the audience for the report. Several pointers are provided in the

NCHRP Report 866 on specific issues that should be kept in mind in preparing the presentation of the results, and in presenting the results of the uncertainty analysis. This completes the procedure outlined and recommended by the NCHRP Report (NCHRP, 2018).

Using the ROI Calculator

In this review, the most important issue is to determine whether or not the ROI tool is potentially useful for assessing the value of TAM systems or procedures for non-road and non-bridge assets such as guardrails, cross drains, impact attenuators, and striping. There seems to be little question that it is applicable to roads and bridges, but other assets may not fit so well. This review is needed to determine applicability of this methodology to the Louisiana situation. At the outset, the report states, "the tool supports analysis of a variety of asset and improvement types," suggesting that it should work for the case of Louisiana (NCHRP, 2018).

The ROI tool assumes that a prospective analysis is being undertaken, where the base case is business as usual, and the investment case is to invest in a TAM system or procedure. This could be applied to a retrospective analysis, simply by setting the start year back at the historic date of the implementation of the TAM system or procedure. Outputs of the ROI tool encompass all the items described in Task 5 of Step 7, previously described in this review. This includes all the ROI metrics. However, a sensitivity analysis would be conducted separately, but could again use the ROI tool to produce the estimates of scenarios, or what-if options.

At a reading level, it appears that the ROI tool should work for any assets, not just road and bridge assets. However, this needs to be confirmed by a trial of the procedure. There is a worked example that is directly relevant to this study. A fictitious state, Alfa, has a DOT that has already invested in TAMs for roads and bridges, but is now considering investing in a system for drainage assets. Based on a review of this example, it appears that the tool is applicable to the non-road, non-bridge assets that DOTD wishes to examine in terms of costs and benefits. Based on this example, a list of required inputs from DOTD staff could be compiled and could then be used to populate the ROI tool.

Appendix F of the NCHRP report provides a detailed description of how this case study was performed by the NCHRP team and provides potentially a guidebook on how the LSU team could go about studying the non-road, non-bridge assets that DOTD is interested in. It would also then provide a means to provide guidance for any future assets that were to be considered for a TAM approach. In Appendix G, there is a checklist of items required for application of the ROI tool. Again, this should be very useful for this project.

The second example relates to a road TAM and is therefore not particularly relevant to this case.

Conclusion on NCHRP 866

There is a very relevant paragraph in the conclusion that applies very well to Louisiana. It is stated:

> **"Better defining benefits of TAM implementation for assets other than pavement and bridges**. Much of the focus in TAM has been on pavement and bridges, as DOTs spend the great majority of their funds on these assets. Consequently, many agencies have already implemented pavement and bridge management systems and are evaluating how best to improve the management of other assets, such as drainage assets, traffic and safety devices, and facilities. The results of this study are fully applicable to these assets, and one of the case studies and the supplemental pilot addressed other assets besides pavement and bridges. Nonetheless, further research may be merited to define specific costs and benefits related to improving management of other asset types." (NCHRP, 2018, p.110).

The research called for here is very relevant to Louisiana. There are also other issues raised in the conclusion that could be very relevant. One of these relates to the frequency of data collection on certain assets and the means of collecting such data. For example, data on cross-drainage systems, impact attenuators, and signs, could all be collected with data currently collected on road and bridge condition. One of the issues not addressed in the NCHRP project is the frequency that data for non-road, non-bridge assets need to be collected. This merits further research. Another area of concern is the goal of the TAM system or procedure. This could be to prevent failure of certain assets such as a cross drain that could result in a temporary road closure while the drain is repaired, or partial closure while the drain is repaired on a lane-by-lane basis. However, other assets may not involve road closures but could lead to increased accidents (e.g., warning road signs that become unreadable at night, or that are too readily ignored because of overall deterioration), or could lead to increased severity of accidents (e.g., if impact attenuators have been damaged or reached the end of their useful life, so their impacts are no longer attenuated). The report notes that there are potential tradeoffs between utility maximizing approaches and regret minimizing approaches for various assets. This also requires further research.

Literature Review Conclusion

In this literature review, there is some very useful information on applying asset management to culverts and to striping on roads. However, the greatest value is probably in the insights provided about the costs of collecting and maintaining data on various assets and the composition of the benefits of collecting data about assets. It is also apparent from the literature reviewed that there is no existing methodology of the type requested by DOTD.

In the future, if it is desired to use the data collected to develop an asset planning procedure for various DOTD assets, the methodology put forward in NCHRP 866 is a good candidate for such a procedure and is recommended for further potential development for Louisiana.

Objective

The principal objective of this research is to provide a consistent methodology to assess and compare the costs of establishing a database on any asset of DOTD, the costs of maintaining the database, and the benefits of creating such a database. The methodology should be able to be applied to any asset that the DOTD may wish to consider in the future and should provide a way to ensure that decisions on whether to collect data on an asset are made in a manner that is consistent across all assets. The goal is to ensure that such future decisions are made in the same way, irrespective of who is making the decisions, and that it can be clear as to the basis for the decision in every case.

Scope

This research should identify the primary aspects of an asset that contribute to the costs of collecting and maintaining data on it and the primary aspects of the benefits of collecting the data on an asset. It is intended that the methodology be applied initially to four assets, namely culverts, guard rails, impact attenuators, and pavement striping. The methodology should be applicable to any asset of the DOTD. These four assets are to be used to illustrate and to test the methodology.

Methodology

Nothing in the literature review showed any methodology of the type requested for this research. Therefore, as a starting point, it was decided to develop essentially three modules—cost of establishing a database on the asset in question, cost of maintaining the database, and benefits of collecting data on the asset. It was required that these modules be defined in such a way that they could be applied to any asset of concern to DOTD. To proceed, the research team developed a description of the factors that would impact the costs in the case of the first two modules and the benefits in the case of the third module. These were used to guide the next step in the process.

The second step in the process was to develop questions that would need to be answered to quantify the levels of cost or benefit within each module. The idea was that an individual, with a sufficiently high level of knowledge and authority for a specific asset, would be asked to respond to certain questions about an asset which would allow determination of the order of magnitude of the costs and benefits. It was assumed that for this methodology the actual determination of the specific dollar costs of each aspect of data collection, and the benefits from collecting data would not be determined. Rather, the goal was to assess the comparative costs and benefits on a three- or five-point scale ranging from “Low” to “High” or “Very Low” to “Very High.”

The questions would also include information about any existing database within DOTD that related to the asset in question as to determine how extensive a new data collection effort would need to be. In addition, because some assets may already have routine data collection undertaken, the extent of such routine data collection needs to be established because it would reduce the cost of maintaining the database. Finally, a group of questions need to be answered to ascertain the benefits of collecting data. These questions, based on the literature review, were mainly focused around the disbenefits arising from unforeseen failures of the asset, which it is assumed would be less likely to occur if a database was being maintained about the asset. Of course, it is an assumption that the database would include data on the condition of each installation of the asset, so that collecting the data on the asset should reduce the likelihood of unforeseen failures.

It should be stressed here that use of the data in an asset management procedure, which was not assumed in this exercise, would be likely to produce much more extensive benefits. However, it was made clear at the outset of the project that this methodology should not assume that asset management procedures would necessarily be put in place because of collection of the data. Therefore, any such benefits were not assumed to be part of the benefits to be assessed. Hence, the benefits really comprise essentially the disbenefits created by not having information about the asset.

The methodology that was then conceived to implement this was to embed the questions in an Excel workbook, in which the responses to the various questions could be used to generate a score for a particular asset. This score would then be used to classify the responses for initial data collection, maintaining the database, and estimating the benefits into the three or five categories ranging from “Low” or “Very Low” to “High” or “Very High.”

A key issue here is to determine how to score the responses to the various questions. If every response is scored identically on a scale (1 through the number of possible responses), then this would generate a rather highly non-discriminating score. To understand this, the point can be illustrated by taking two of the attributes of an asset and comparing the scores.

For example, suppose that one of the attributes of importance is the number of locations of the asset throughout the state, and the second attribute is how detailed an examination must be made of each installation of the asset to determine its current condition. Suppose that the number of locations is classified into the following groups:

1. In only one or two locations
2. In a few specific locations
3. Along specific state or federal highways
4. Along many state and federal highways
5. Along all state and federal highways

For example, sound walls that are only found in a few locations on interstate routes, so might fall into category 2, compared to cross drains that occur along all federal and state highways.

A second attribute of the level of inspection might be divided into the following categories:

1. Cursory inspection from a moving vehicle
2. Brief examination of less than 1 hour per installation

3. A detailed examination of more than 1 hour per installation
4. A detailed examination with testing requiring more than 2 hours per installation

For example, cross drains may require a detailed field examination to determine condition including a possible test to determine the flow rate of water through the drain. Pavement markings may require only a cursory examination, which could be done with video, from a moving vehicle.

Suppose now that the five levels of location are scored from 1 through 5, and the four levels of examination are scored from 1 through 4. Scores could range for these two attributes from 2 to 9. However, a score of 5, for example, could be obtained from each of the following cases:

1. An asset that occurs in only one or two locations but requires detailed examination and testing.
2. An asset that occurs in a few specific locations and requires detailed examination lasting more than 1 hour per location.
3. An asset that occurs along specific state or federal highways and requires only a brief examination lasting less than 1 hour.
4. An asset that occurs along many state and federal highways and requires only cursory examination.

It does not seem likely that all four situations are roughly identical in cost for collecting or maintaining data. As the number of attributes is expanded beyond two, the incidence of the same score arising from multiple scenarios will increase, further suggesting that the real nonequivalence of the scores would be a major issue. To resolve this issue, it was decided that an attempt should be made to describe the most likely scenarios through a combination of attribute levels on each attribute of an asset, and to seek for scores on the attributes that would distinguish most, if not all, scenarios from one another, (i.e., that each scenario would be associated with an unique score, where that score showed some relationship to expected levels of cost or benefit). The primary guidance in creating the scores would be that higher scores would be associated with more expensive situations, or scenarios with higher disbenefits from not collecting data on a routine basis. Beyond this, no guidance could be given.

The final step in the methodology would be to use the scores to produce a summary of the information, and compute the levels of costs and benefits in a concise manner to guide the decisions of DOTD officials. There should be some flexibility in determining the boundaries between each level of cost or benefit. In this research, the five levels of cost and benefit describes a bell-shaped distribution. That is, the “Medium” levels should have the most scenario occurrences, and the extremes of “Very Low” and “Very High” should be associated with the fewest scenario occurrences.

Discussion of Results

Factors Affecting Costs and Benefits

Module 1: Evaluate Data Collection Costs

Several factors influence the cost of collecting data on different assets. Among those are:

1. Whether or not DOTD or any other statewide agency already has a complete inventory. The existence of such an inventory, even if it is not current, provides a base for updating and maintaining data. For example, a complete record may exist in the state DOT of every traffic signal installed on the state highway system and U.S. routes, having been created by recording when each installation was originally undertaken.
2. Whether or not the inventory can be added into an existing routine inventory. For example, the state uses Automatic Road Analyzer (ARAN) to collect data for pavement management purposes. This is done on an annual basis. Whether this covers the entire state each year or covers only a part of the state each year needs to be determined. Additional asset data could potentially be extracted from the ARAN records, although this may be a labor-intensive task, unless image-recognition programming can be deployed to provide the needed data.
3. How many or how much of the asset exists in the state. For example, there are relatively few interstate signs, while there are many traffic signals.
4. The geographic extent of the asset. Is the asset concentrated in a few locations or is it throughout the state? Sound walls are found in very few locations within cities in the state and primarily or solely along interstate highways. In contrast, culverts and cross-drains are found throughout the state and on every roadway.
5. How rapidly the asset deteriorates. Some assets like sign gantries may have an expected life of 40 to 50 years, while pavement striping only has an expected life of one to three years. If an asset has a long life, it is probably necessary to create a new inventory because records of installation, or most recent maintenance activity either may not exist or may be sufficiently old that they do not provide an adequate basis for an inventory. This may be the case for culverts and cross drains. On the other hand, if the asset has a very short life, the inventory may be

able to be constructed from the records of replacement, such as in the case of pavement striping.

6. Whether the state of repair can be assessed from a drive-by observation or it is necessary to inspect the asset to determine the state of repair. Cable crash barriers can probably be assessed from driving along roadways and observing the state of repair of the crash barriers. However, other types of crash barrier require inspection of both the front and back of the crash barrier and, therefore, require a much more labor-intensive inspection.
7. Whether it is likely that data can be collected by DOTD staff or if a contract is likely to need to be let to collect the data. It may, for example, be quite feasible to have DOTD staff periodically collect data on the state of repair of freeway signs. In contrast, a full inspection of all culverts and cross drains is likely to require a contract with an outside firm to accomplish the inventory in a reasonable time frame.
8. Whether records of contracts let to construct or maintain an asset can provide the basis for an inventory. For example, if all traffic signals are installed under contract and records exist of all traffic signal contracts, then the age of every signal installation could be extracted to form an inventory. This inventory could be modified further by extracting information on whether a contract has been let, subsequent to initial installation, to maintain, repair, or update each traffic signal installation. However, if traffic signals are sometimes installed under contract and, at other times, are installed by in-house DOTD staff, the records may not be able to be extracted to provide a comprehensive inventory.
9. What needs to be known about an asset to provide the necessary inventory. The locations of the asset and the age of the asset are clearly required. In some cases, information is also needed on the date of the last repair/updating/replacement of an asset. The type of material used will sometimes be a required item of data. Other data that may be required, depending on the nature of the asset, are the: ownership of the asset; estimated energy use (e.g., for traffic signals); the quality of the original installation; fabrication quality; traffic hits; exposure to strong winds or to floods; likelihood of fatigue; and environmental factors that may affect the state of repair.
10. The method by which data are currently recorded. Data on some assets may exist only on paper or in a spreadsheet, while other data may be recorded in an asset management database. The extent to which paper or computer records must be

searched and data digitized or extracted from an older digital system will affect the cost of data collection.

11. For some assets, data may be required on the capacity of the assets. For example, the current capacities of culverts and cross drains would be required to determine whether adequate capacity is currently available or if the capacity is being routinely exceeded. In the case of crash barriers, the ability of the crash barrier to handle crashes of larger and heavier vehicles may be needed, to assess the adequacy of the existing barriers. A similar issue may arise with crash attenuators.

12. The extent to which data on performance of the asset is required. For example, for both signs and pavement markings, the current level of reflectivity is crucial to determining if the asset is meeting performance criteria. In the case of culverts and cross drains, the extent to which water flows through the culvert or cross drain is also crucial to determining if the asset is currently meeting performance requirements. This may require the use of specialized equipment to determine the current performance level of some assets, including such assets as signs, pavement markings, culverts, cross drains, traffic signals, etc.

Module 2: Evaluate Data Maintenance Costs

Similarly, several factors affect the costs of maintaining data on different assets. Among these are:

1. The frequency with which the asset is normally scheduled for replacement. Data on an asset such as pavement striping, which may be scheduled for replacement every two to three years or more frequently, may be able to be updated from records made of replacement. Other assets that may have a life of 25 years or more may require a periodic updating of the database to record deterioration and performance. Assets like culverts and cross drains would likely fall into this category.

2. Who is responsible for maintenance and replacement, refurbishment, or updating of the asset? For assets that are maintained, replaced, refurbished, or updated by DOTD staff, it should be a relatively simple requirement to have details of the effects of such maintenance, replacement, refurbishment, or updates entered into a common database within DOTD, which could be incorporated into the asset management database. However, for assets where any of these activities are normally performed by private firms or others outside DOTD, it would be necessary to include a requirement in the contract to record information in the

asset management database that is pertinent to asset management. These data would include similar data to what is required for the original database, including the materials used, the location and extent, the nature of the work done, etc.

3. Whether the asset is subject to catastrophic events that would result in significant damage or can be assumed to deteriorate at a known or estimated rate. Many assets of DOTD are subject to catastrophic events, such as traffic crashes that can result in damage or demolition of the asset. The frequency of such catastrophic events and the extent to which repair or replacement must be scheduled immediately will affect the cost of maintaining the database. For example, an asset that can affect traffic flow upon failure would usually be targeted for immediate replacement or repair, whereas an asset that has little or no effect on traffic flow, and crashes may be left until other nearby maintenance is scheduled. The former should be readily captured into the asset management database. The latter would require additional effort to record the state of repair in the asset management database.
4. What is involved in collecting the data for updating the database. Items 3, 4, 6, 9, and 10 from Module 1 will also come into play in the costs of maintaining the database.
5. Who maintains the database currently also impacts the cost to DOTD of maintaining and updating the database. If it is owned and updated by DOTD staff, then this will be a lower cost than if the database is normally maintained through a contract.

Module 3: Evaluate Benefits

The benefits of collecting and maintaining the data on different assets will also be influenced by several factors. Among these are:

1. Knowledge of the state of good repair (SOGR) of assets in the system.
2. Reduce catastrophic failures that can lead to a reduction in safety. While it is likely that almost all DOTD assets have some impact on safety of operation of the state's roadways, the extent to which safety is impacted may vary significantly. For example, deterioration of pavement markings may impact safety to a limited extent but is probably unlikely to lead to a significant increase in the number or severity of crashes when it is worn away to the point of not being visible. In contrast, a speed limit sign or other sign indicating a mandatory requirement on

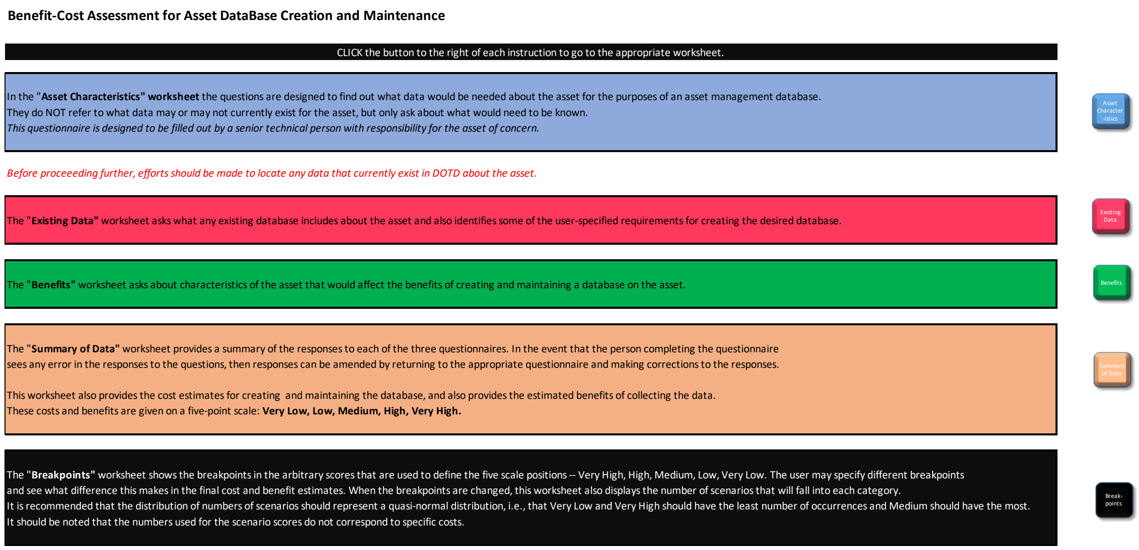
drivers, if destroyed in a crash, could lead to both more crashes and more severe crashes in the locality of the sign. Instituting repairs ahead of a marked reduction in safety is a benefit.

3. Reduce the frequency of failure that is likely to result from the state not knowing the state of repair of the asset. For example, a culvert that becomes clogged with debris may result in water damage to the roadway and to an eventual failure of the pavement, through such mechanisms as washing out of the foundation of the roadbed. Ignorance of the state of repair of culverts could therefore lead to more frequent failures that could have been avoided if information was available on the state of repair and maintenance activities scheduled that would delay and reduce the frequency of repairs.
4. Increase the lifecycle of an asset from routine maintenance and repair of minor damage. If the life of an asset could be extended through knowledge of the state of repair, scheduling repair of minor damage, and a program of routine maintenance, then the benefit to the state may be considerable in terms of avoiding loss of value of the asset.
5. Reduce the costs to the state resulting from a failure of the asset. That is, make more efficient use of funds by repairing an asset when it is most cost-effective to do so. Some assets, if they fail, may result in road closures while repair is undertaken or, in some cases, lane closures. These may be costly to users of the state’s roadway systems, especially for freight movements by road. These may include such assets as culverts and cross drains. Other assets may incur little or no cost to users while repair or replacement is undertaken. This may be true for crash attenuators and most crash barriers. Determining the size and nature of benefits to the state of maintaining a database on an asset, where these benefits arise from periodic and avoidable failure of the asset are a significant contributor to the size of the benefits that will arise from the asset data.

Definition of Questions and Response Sets

The questions and responses were coded into an Excel workbook, so that the user can respond to the questions and obtain an estimate of the costs and benefits of the database creation and maintenance. The workbook, “Estimation of Costs and Benefits of Asset Data Collection v2-2.xls,” contains six protected worksheets and four hidden worksheets. The latter are used in producing the cost and benefit estimates but have nothing for the user to input and are protected from being unhidden. Appendix A provides detailed instructions for using the workbook. The first worksheet provides instructions for using the workbook and is shown in Figure 3.

Figure 3. Instruction page of Excel workbook for estimating costs and benefits of data collection


Benefit-Cost Assessment for Asset DataBase Creation and Maintenance

CLICK the button to the right of each instruction to go to the appropriate worksheet.

In the "**Asset Characteristics" worksheet** the questions are designed to find out what data would be needed about the asset for the purposes of an asset management database.
They do NOT refer to what data may or may not currently exist for the asset, but only ask about what would need to be known.
This questionnaire is designed to be filled out by a senior technical person with responsibility for the asset of concern.

Asset Character -istics

Before proceeeding further, efforts should be made to locate any data that currently exist in DOTD about the asset.

The "**Existing Data"** worksheet asks what any existing database includes about the asset and also identifies some of the user-specified requirements for creating the desired database.

Existing Data

The "**Benefits"** worksheet asks about characteristics of the asset that would affect the benefits of creating and maintaining a database on the asset.

Benefits

The "**Summary of Data"** worksheet provides a summary of the responses to each of the three questionnaires. In the event that the person completing the questionnaire sees any error in the responses to the questions, then responses can be amended by returning to the appropriate questionnaire and making corrections to the responses.

This worksheet also provides the cost estimates for creating and maintaining the database, and also provides the estimated benefits of collecting the data.
These costs and benefits are given on a five-point scale: **Very Low, Low, Medium, High, Very High.**

Summary of Data

The "**Breakpoints"** worksheet shows the breakpoints in the arbitrary scores that are used to define the five scale positions -- Very High, High, Medium, Low, Very Low. The user may specify different breakpoints and see what difference this makes in the final cost and benefit estimates. When the breakpoints are changed, this worksheet also displays the number of scenarios that will fall into each category.
It is recommended that the distribution of numbers of scenarios should represent a quasi-normal distribution, i.e., that Very Low and Very High should have the least number of occurrences and Medium should have the most.
It should be noted that the numbers used for the scenario scores do not correspond to specific costs.

Break-points

The instructional boxes are color-coded to the colors of the tabs in the workbook. Although taking them out of order will not create fatal errors, the user should proceed through the worksheets in order provided that the Summary of Data is not examined until after the preceding three worksheets have been completed.

The first step in this procedure was seen to determine what ideally should be known about an asset and to permit the definition of the data to be collected. Six primary attributes were defined as being necessary to determine what should be in the data describing the asset:

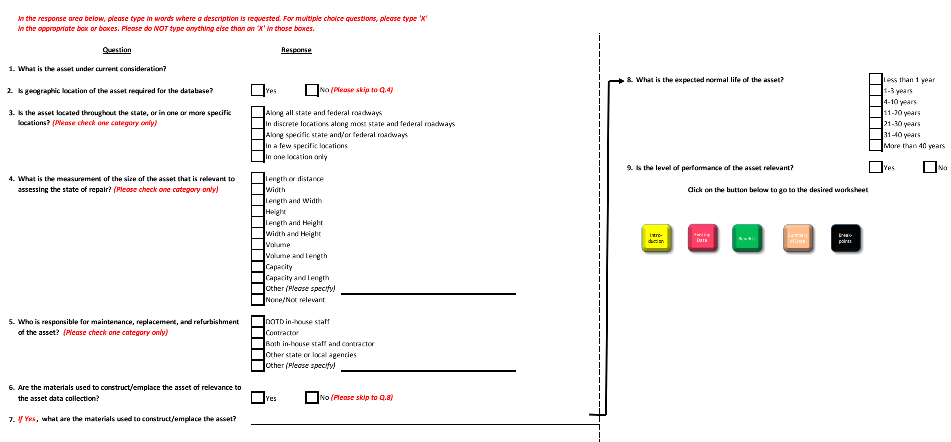
1. Physical location of the asset and whether it was necessary to know the location.
2. The measurement of the asset that was relevant for data collection, e.g., length, width, height, volume, or capacity, etc.
3. Responsibility for maintenance, replacement, or refurbishment of the asset, e.g., in-house staff, contractor, etc.
4. If relevant, the materials from which the asset is constructed in various locations, which would probably be important only when different materials may be used in different installations of the asset.

5. The normal expected life of the asset.
6. Whether the level of performance of the asset is needed to assess the condition.

It was felt that these questions should be able to be answered by a senior management person in DOTD who had direct responsibility for the asset, or someone in DOTD who was knowledgeable about the asset. In then assessing any existing data on the asset, these questions could be used to determine if further data collection would be required, as well as, in some cases, defining the cost range for acquiring the data. Based on this, the first question module was defined as shown in Figure 4. This constitutes the second worksheet in the workbook and has a blue tab.

The next set of questions were designed to define what, if any, data already existed about the asset. Before answering these questions, it was intended that the person filling out the questionnaire would determine if a database already existed on the asset and would know where it was located.

Figure 4. Attributes of the asset of importance to assessing costs of data collection


In the response area below, please type in words where a description is requested. For multiple choice questions, please type 'X' in the appropriate box or boxes. Please do NOT type anything else than an 'X' in those boxes.

Question / Response

1. What is the asset under current consideration?
2. Is geographic location of the asset required for the database? ☐ Yes ☐ No *(Please skip to Q.4)*
3. Is the asset located throughout the state, or in one or more specific locations? *(Please check one category only)*
   - ☐ Along all state and federal roadways
   - ☐ In discrete locations along most state and federal roadways
   - ☐ Along specific state and/or federal roadways
   - ☐ In a few specific locations
   - ☐ In one location only
4. What is the measurement of the size of the asset that is relevant to assessing the state of repair? *(Please check one category only)*
   - ☐ Length or distance
   - ☐ Width
   - ☐ Length and Width
   - ☐ Height
   - ☐ Length and Height
   - ☐ Width and Height
   - ☐ Volume
   - ☐ Volume and Length
   - ☐ Capacity
   - ☐ Capacity and Length
   - ☐ Other *(Please specify)* ____________
   - ☐ None/Not relevant
5. Who is responsible for maintenance, replacement, and refurbishment of the asset? *(Please check one category only)*
   - ☐ DOTD in-house staff
   - ☐ Contractor
   - ☐ Both in-house staff and contractor
   - ☐ Other state or local agencies
   - ☐ Other *(Please specify)* ____________
6. Are the materials used to construct/emplace the asset of relevance to the asset data collection? ☐ Yes ☐ No *(Please skip to Q.8)*
7. *If Yes*, what are the materials used to construct/emplace the asset? ____________
8. What is the expected normal life of the asset?
   - ☐ Less than 1 year
   - ☐ 1-3 years
   - ☐ 4-10 years
   - ☐ 11-20 years
   - ☐ 21-30 years
   - ☐ 31-40 years
   - ☐ More than 40 years
9. Is the level of performance of the asset relevant? ☐ Yes ☐ No

Click on the button below to go to the desired worksheet

Intro-duction | Existing Data | Benefits | Summary of Data | Break-points

The questions to be answered about the existing data would help to define what was missing and whether the existing data already constituted an acceptable database about the asset. The questions that were defined as being necessary for this were:

1. Whether an existing dataset was found for this asset.
2. If it is,
   a. Where it is located, and the name of the dataset are requested next.

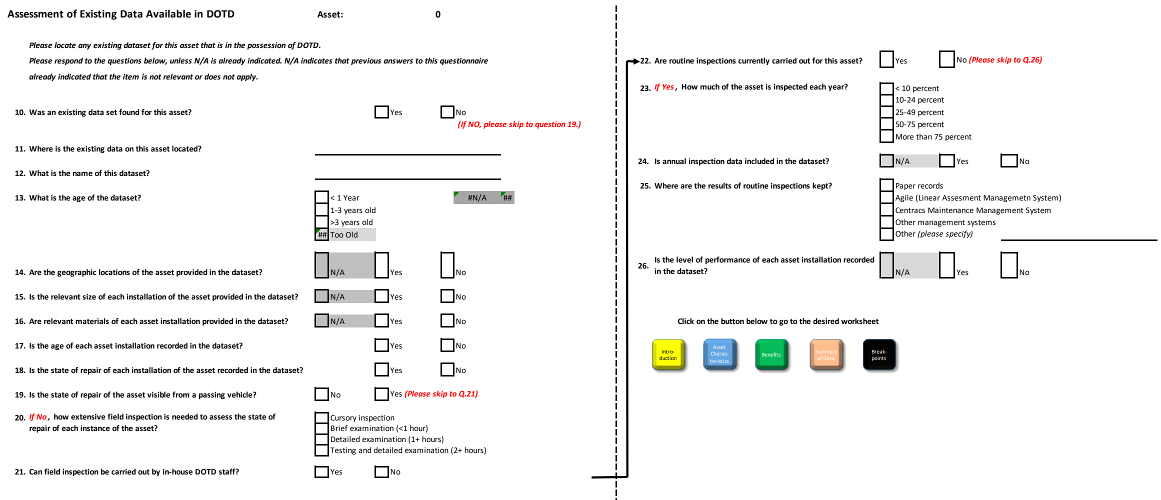
b. The age of the dataset is requested next.
c. Details of the information available in the dataset are then requested:
    i. Geographic locations, if applicable.
    ii. Relevant size of the asset installations.
    iii. Relevant materials of which the asset is constructed.
    iv. The age of each installation of the asset.
    v. The state of repair of each installation of the asset.

3. The next questions relate to the visibility of the state of repair, what sort of examination is required to establish the state of repair, and whether these examinations can be carried out by DOTD staff.
4. The next four questions relate to whether routine inspections are currently carried out, the amount of the asset in the state that is inspected each year, whether the inspection data are included in the dataset, and where the routine inspection results are kept.
5. The final question asks whether the level of performance of the asset is recorded in the database.

The questionnaire is shown in Figure 5 and comprises the third worksheet in the workbook and has a tab that is colored red. It should be noted that, if there is no database found for the asset, then most of the questions on this sheet will be skipped. The only questions of relevance will be those relating to inspection and level of performance.

The final set of questions deal with the potential benefits of collecting the data on the asset. Because the only assumption about use that can be made at this stage relates to the knowledge provided about the asset, the benefits concentrate on those benefits that would arise from avoidance of unexpected failure of the asset.

Figure 5. Questions relating to an existing database



Assessment of Existing Data Available in DOTD **Asset:** **0**

Please locate any existing dataset for this asset that is in the possession of DOTD.
Please respond to the questions below, unless N/A is already indicated. N/A indicates that previous answers to this questionnaire already indicated that the item is not relevant or does not apply.

10. Was an existing data set found for this asset? ☐ Yes ☐ No *(If NO, please skip to question 19.)*

11. Where is the existing data on this asset located? ________

12. What is the name of this dataset? ________

13. What is the age of the dataset? ☐ < 1 Year ☐ 1-3 years old ☐ >3 years old ## Too Old #N/A ##

14. Are the geographic locations of the asset provided in the dataset? ☐ N/A ☐ Yes ☐ No

15. Is the relevant size of each installation of the asset provided in the dataset? ☐ N/A ☐ Yes ☐ No

16. Are relevant materials of each asset installation provided in the dataset? ☐ N/A ☐ Yes ☐ No

17. Is the age of each asset installation recorded in the dataset? ☐ Yes ☐ No

18. Is the state of repair of each installation of the asset recorded in the dataset? ☐ Yes ☐ No

19. Is the state of repair of the asset visible from a passing vehicle? ☐ No ☐ Yes *(Please skip to Q.21)*

20. *If No*, how extensive field inspection is needed to assess the state of repair of each instance of the asset? ☐ Cursory inspection ☐ Brief examination (<1 hour) ☐ Detailed examination (1+ hours) ☐ Testing and detailed examination (2+ hours)

21. Can field inspection be carried out by in-house DOTD staff? ☐ Yes ☐ No

22. Are routine inspections currently carried out for this asset? ☐ Yes ☐ No *(Please skip to Q.26)*

23. *If Yes*, How much of the asset is inspected each year? ☐ < 10 percent ☐ 10-24 percent ☐ 25-49 percent ☐ 50-75 percent ☐ More than 75 percent

24. Is annual inspection data included in the dataset? ☐ N/A ☐ Yes ☐ No

25. Where are the results of routine inspections kept? ☐ Paper records ☐ Agile (Linear Assesment Managemetn System) ☐ Centracs Maintenance Management System ☐ Other management systems ☐ Other *(please specify)* ________

26. Is the level of performance of each asset installation recorded in the dataset? ☐ N/A ☐ Yes ☐ No

Click on the button below to go to the desired worksheet

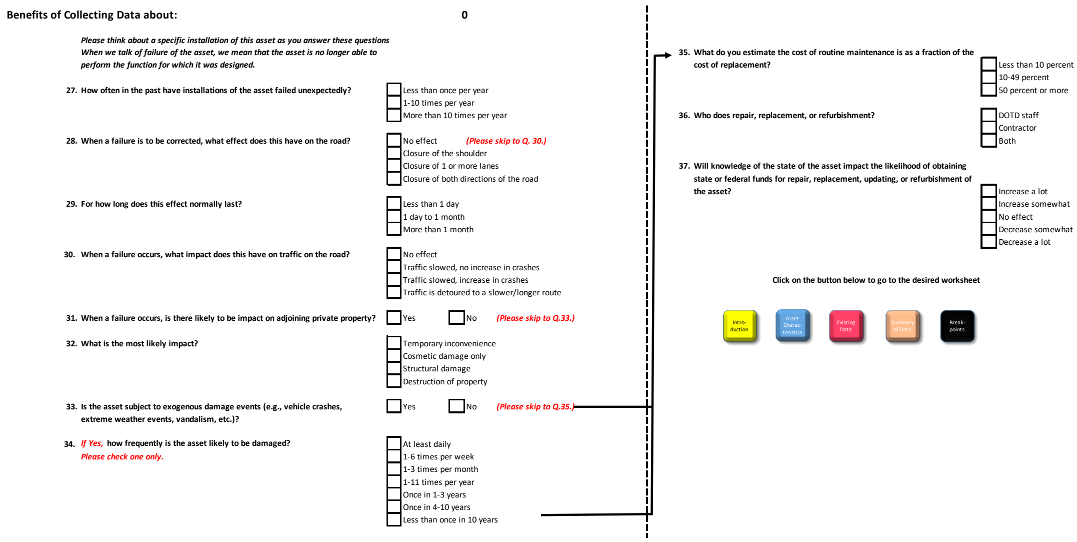
Intro-duction | Asset Charac-teristics | Benefits | Summary of Data | Break-points

The questions to be answered cover the following issues:

1. The frequency of past failures of the asset.
2. When a failure occurs, what is the effect of the failure on the road and on traffic?
3. Further, what effect does failure have on adjoining private property (e.g., flooding from a collapsed or blocked cross drain, collapse of the building because of a retaining wall failure, etc.)?
4. Whether the asset is liable to exogenous damage, such as from storms, crashes, etc.
5. The cost of routine maintenance as a percentage of the replacement cost.
6. Who is responsible for repairing, replacing, or refurbishing the asset?
7. Whether having data on the asset will increase or decrease the likelihood of funding for the asset.

This part of the questionnaire is shown in Figure 6 and comprises the fourth worksheet in the workbook and has a green tab.

Figure 6. Questions on the benefits of collecting asset data


Benefits of Collecting Data about: 0

Please think about a specific installation of this asset as you answer these questions
When we talk of failure of the asset, we mean that the asset is no longer able to perform the function for which it was designed.

27. How often in the past have installations of the asset failed unexpectedly?
- Less than once per year
- 1-10 times per year
- More than 10 times per year

28. When a failure is to be corrected, what effect does this have on the road?
- No effect *(Please skip to Q. 30.)*
- Closure of the shoulder
- Closure of 1 or more lanes
- Closure of both directions of the road

29. For how long does this effect normally last?
- Less than 1 day
- 1 day to 1 month
- More than 1 month

30. When a failure occurs, what impact does this have on traffic on the road?
- No effect
- Traffic slowed, no increase in crashes
- Traffic slowed, increase in crashes
- Traffic is detoured to a slower/longer route

31. When a failure occurs, is there likely to be impact on adjoining private property?
- Yes
- No *(Please skip to Q.33.)*

32. What is the most likely impact?
- Temporary inconvenience
- Cosmetic damage only
- Structural damage
- Destruction of property

33. Is the asset subject to exogenous damage events (e.g., vehicle crashes, extreme weather events, vandalism, etc.)?
- Yes
- No *(Please skip to Q.35.)*

34. *If Yes,* how frequently is the asset likely to be damaged? *Please check one only.*
- At least daily
- 1-6 times per week
- 1-3 times per month
- 1-11 times per year
- Once in 1-3 years
- Once in 4-10 years
- Less than once in 10 years

35. What do you estimate the cost of routine maintenance is as a fraction of the cost of replacement?
- Less than 10 percent
- 10-49 percent
- 50 percent or more

36. Who does repair, replacement, or refurbishment?
- DOTD staff
- Contractor
- Both

37. Will knowledge of the state of the asset impact the likelihood of obtaining state or federal funds for repair, replacement, updating, or refurbishment of the asset?
- Increase a lot
- Increase somewhat
- No effect
- Decrease somewhat
- Decrease a lot

Click on the button below to go to the desired worksheet

Intro-duction | Asset Charac-teristics | Existing Data | Summary of Data | Break-points

The answers to these three questionnaires are then summarized on the fifth worksheet in the workbook, as shown in Figure 7. This worksheet, which has a buff-colored tab, also computes the levels of cost for creating and maintaining the database, and provides the level of benefit from collecting the data. There is nothing that the user can fill in directly in this fifth worksheet. All answers are obtained from the three preceding worksheets and computed from those results. The print area has been set to the five colored boxes on this worksheet and can be printed out by the user. The print setting should be landscape and to fit to size.

By playing back the responses to the various questions, the user can also review those responses, and may return to a specific worksheet to modify an answer if it appears that the answer is not correct. Alternatively, if there is more than one possible answer to some of the questions, the user can experiment with the sensitivity of the workbook to these differing answers.

Figure 7. Summary of results

Asset: 0

Asset Data Description		
2.	Spatial Location:	Required
3.	Locations:	#N/A
4.	Required Measurements:	#N/A
5.	Responsibility for Asset:	#N/A
6.	Materials Relevant:	Yes
7.	What Materials:	
8.	Normal Life of the Asset:	#N/A
9.	Level of performance needed:	No

Database Maintenance Requirements		
3.	Number of Locations	#N/A
22.	Routine inspections carried out	No
24.	Routine Inspections on Computer	N/A
23.	At least 10% inspected per year	#N/A
8.	Asset Life	#N/A
21.	In-house Staff or Contractor	Contractor
20.	Extent of required inspection	In-vehicle
	Score	#N/A
	Cost	#N/A

Data Requirements		
10.	Database exists and is not too old	#N/A
11.	Located in:	#N/A
12.	Database in:	#N/A
13.	Database is too old	#N/A
14.	Location of Assets Included	#N/A
3.	Number of Locations	#N/A
15.	Relevant Size	Needed
16.	Relevant Materials	Needed
17.	Age of Asset	Needed
18.	State of Repair	Needed
19.	Visible State of Repair:	No
20.	Type of inspection required:	In-vehicle
21.	In-house inspection?	No
22.	Routine Inspections are carried out:	No
23.	Amount of Asset inspected annually:	#N/A
24.	Inspection Data in dataset?	N/A
25.	Location of Annual Inspection Data:	#N/A
26.	Level of Performance	Needed
	TOTAL SCORE	#N/A
	Cost	#N/A

Benefits		
27.	Unexpected Failure Frequency	#N/A
28.	Failure effect on the road	#N/A
29.	Length of time of road effect	#N/A
30.	Failure effect on traffic	#N/A
31.	Is private property impacted	No
32.	How much is it impacted	No private property damage
33.	Subject to damage:	No
34.	Expected frequency of damage:	Not subject to damage
35.	Routine maintenance:replacement cost	#N/A
36.	Who repairs or replaces	Both
37.	Change likelihood of funding	#N/A
	Score	#N/A
	Benefit	#N/A

FINAL RESULTS	
Cost to create data set	#N/A
Cost to Maintain Database	#N/A
Estimated Benefits	#N/A

Click on the button to go to the desired worksheet

Intro-duction | Asset Charac-teristics | Existing Data | Benefits | Break-points

In the red box titled Data Requirements, answers to questions 14 through 18 and 26 will show "Available" if a dataset was found and the item was included in the dataset. If the item was indicated in "Asset Characteristics" as one that was not required, then "Not Needed" will show in responses 14 through 18 and 26; and if the item is required but there is no dataset or there is a dataset, but it does not include the item, then the response "Needed" will be shown. Most of the other responses are self-explanatory and correspond to the answer categories on the previous worksheets.

The levels of cost and benefit are provided on a five-point scale of "Very High" through "Very Low." The user is also provided on the final worksheet a listing of the breakpoints used to distinguish the different levels of cost and benefit. These breakpoints should be kept to an approximately normal distributions—the highest number of scenarios being in the "Medium" category; approximately equal numbers in "Low" and "High" categories; and approximately equal but smaller numbers in the "Very Low" and "Very High" categories. The default set of breakpoints is shown in Figure 8, which has a black tab. Again, the fact that the breakpoints can be shifted by the user permits some sensitivity testing of the assumptions made and the answers provided.

Figure 8. Breakpoints for discriminating among the levels of cost and benefit

Breakpoints for Assessing Costs and Benefits of Assets

Break points for Initial Cost

			Percent of Scenarios
12	Very Low	76	6.4%
25	Low	198	16.6%
100	Medium	635	53.3%
131	High	208	17.4%
	Very High	75	6.3%

Breakpoints for Data Maintenance

			Percent of Scenarios
38	Very Low	7	7.8%
80	Low	16	17.8%
160	Medium	44	48.9%
210	High	16	17.8%
	Very High	7	7.8%

Breakpoints for Benefits

			Percent of Scenarios
300	Very Low	284	4.5%
700	Low	963	15.3%
3100	Medium	2476	39.4%
4300	High	986	15.7%
	Very High	286	4.6%

Click on the button below to go to the desired worksheet

Intro-duction | Asset Charac-teristics | Existing Data | Benefits | Summary of Data

The scoring of the various answers were selected to provide the lowest possible replication of scores among possible scenarios. The scores distinguish appropriately between answers that were expected to generate significant/small costs or benefits. To arrive at these, all possible scenarios were constructed for each of the creation of the database, the maintenance of the database, and the estimation of the benefits. This involved many scenarios, especially in the case of the benefits. For the costs of creating the database, 1,200 scenarios were defined while 90 scenarios were defined for the maintenance of the database. The benefits created a much larger number of potential scenarios with 4,995 possible outcomes from the set of questions used. These are contained in a hidden worksheet in the workbook. However, the workbook structure is locked so that only authorized users can unhide the hidden worksheets.

Results of Tests of the Workbook

Several tests were undertaken of the workbook to determine how it performed and to see if there were issues that needed to be resolved. In early tests, several issues came to light that were added to the workbook or that resulted in changes within the workbook. Some of the results of these tests are documented in this section.

Culverts and Cross Drains

The first test was done with culverts and cross drains. Completion of the first worksheet is shown in Figure 9.

Figure 9. Completion of the first worksheet – asset characteristics – for culverts and cross drains

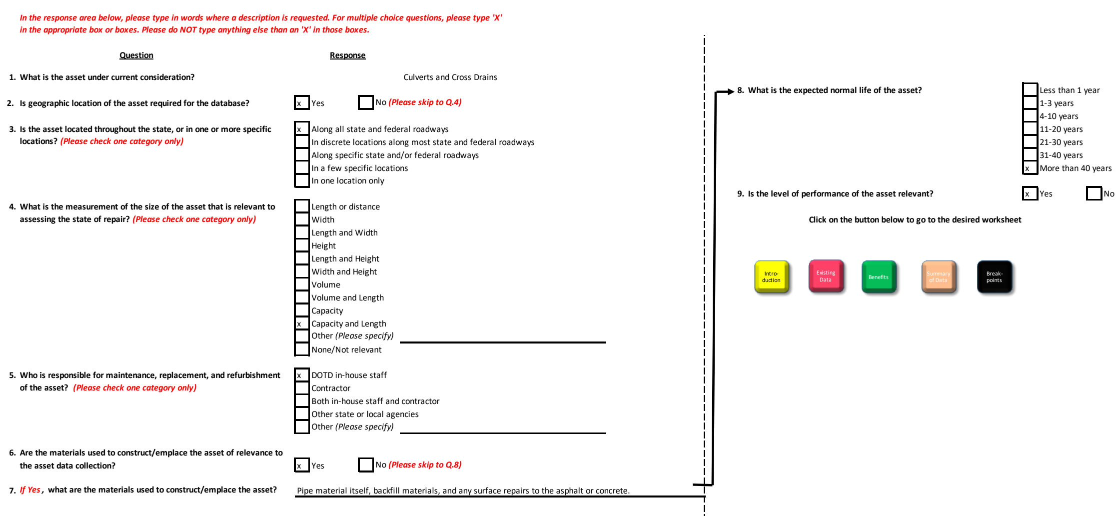
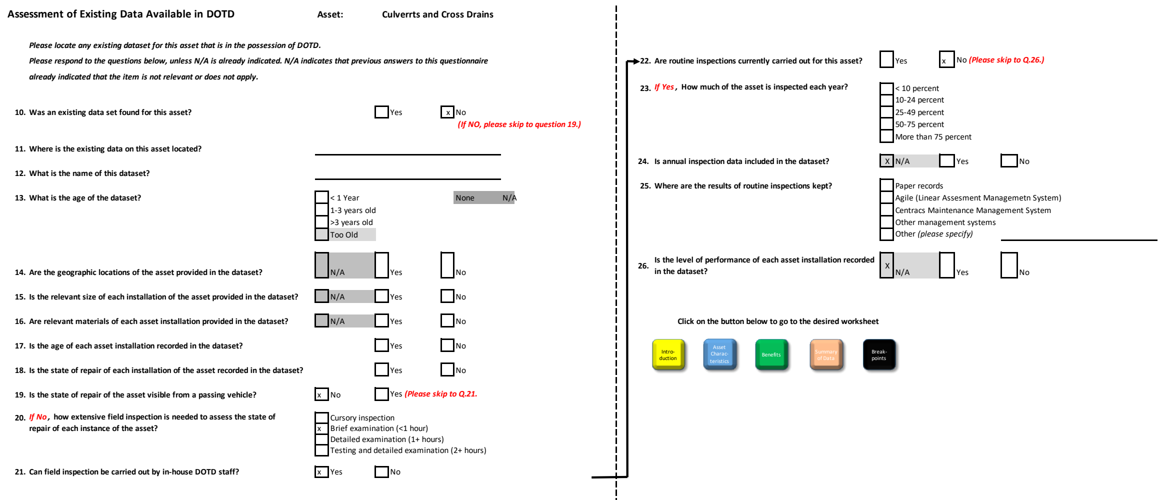


Figure 10 shows that there is no known dataset in existence for culverts and cross drains.

Figure 10. Completion of the second worksheet – existing data – for culverts and cross drains



Assessment of Existing Data Available in DOTD   Asset: Culverts and Cross Drains

Please locate any existing dataset for this asset that is in the possession of DOTD.
Please respond to the questions below, unless N/A is already indicated. N/A indicates that previous answers to this questionnaire already indicated that the item is not relevant or does not apply.

10. Was an existing data set found for this asset? ☐ Yes ☒ No *(If NO, please skip to question 19.)*
11. Where is the existing data on this asset located?
12. What is the name of this dataset?
13. What is the age of the dataset? ☐ < 1 Year ☐ 1-3 years old ☐ >3 years old ☐ Too Old   None   N/A
14. Are the geographic locations of the asset provided in the dataset? ☐ N/A ☐ Yes ☐ No
15. Is the relevant size of each installation of the asset provided in the dataset? ☐ N/A ☐ Yes ☐ No
16. Are relevant materials of each asset installation provided in the dataset? ☐ N/A ☐ Yes ☐ No
17. Is the age of each asset installation recorded in the dataset? ☐ Yes ☐ No
18. Is the state of repair of each installation of the asset recorded in the dataset? ☐ Yes ☐ No
19. Is the state of repair of the asset visible from a passing vehicle? ☒ No ☐ Yes *(Please skip to Q.21.)*
20. *If No*, how extensive field inspection is needed to assess the state of repair of each instance of the asset? ☐ Cursory inspection ☒ Brief examination (<1 hour) ☐ Detailed examination (1+ hours) ☐ Testing and detailed examination (2+ hours)
21. Can field inspection be carried out by in-house DOTD staff? ☒ Yes ☐ No

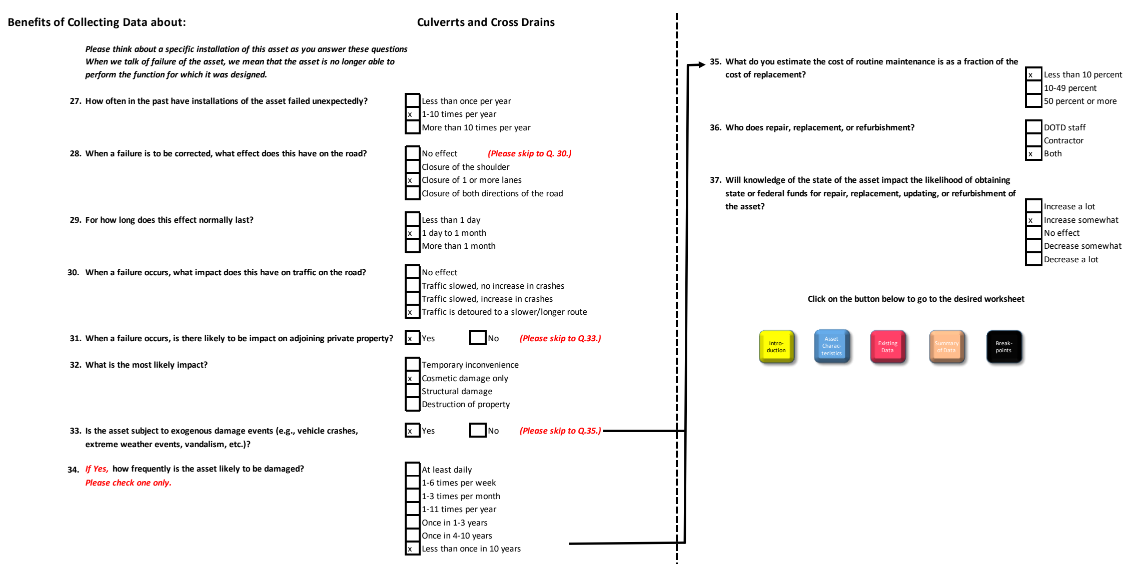
22. Are routine inspections currently carried out for this asset? ☐ Yes ☒ No *(Please skip to Q.26.)*
23. *If Yes*, How much of the asset is inspected each year? ☐ < 10 percent ☐ 10-24 percent ☐ 25-49 percent ☐ 50-75 percent ☐ More than 75 percent
24. Is annual inspection data included in the dataset? ☒ N/A ☐ Yes ☐ No
25. Where are the results of routine inspections kept? ☐ Paper records ☐ Agile (Linear Assesment Managemetn System) ☐ Centracs Maintenance Management System ☐ Other management systems ☐ Other *(please specify)*
26. Is the level of performance of each asset installation recorded in the dataset? ☒ N/A ☐ Yes ☐ No

Click on the button below to go to the desired worksheet

Intro-duction | Asset Charac-teristics | Benefits | Summary of Data | Break-points

Looking at the responses to the existing data and asset characteristic data, it would be expected that the costs of creating the database would be in the medium-to-high range mainly because the asset is found along all state and federal roadways; also, because at least a brief examination is considered necessary, but can be done by DOTD staff. Figure 11 shows the completion of the third worksheet for the benefits.

Figure 11. Completion of the third worksheet – benefits – for culverts and cross drains



Benefits of Collecting Data about: Culverts and Cross Drains

Please think about a specific installation of this asset as you answer these questions
When we talk of failure of the asset, we mean that the asset is no longer able to perform the function for which it was designed.

27. How often in the past have installations of the asset failed unexpectedly? ☐ Less than once per year ☒ 1-10 times per year ☐ More than 10 times per year
28. When a failure is to be corrected, what effect does this have on the road? ☐ No effect *(Please skip to Q. 30.)* ☐ Closure of the shoulder ☒ Closure of 1 or more lanes ☐ Closure of both directions of the road
29. For how long does this effect normally last? ☐ Less than 1 day ☒ 1 day to 1 month ☐ More than 1 month
30. When a failure occurs, what impact does this have on traffic on the road? ☐ No effect ☐ Traffic slowed, no increase in crashes ☐ Traffic slowed, increase in crashes ☒ Traffic is detoured to a slower/longer route
31. When a failure occurs, is there likely to be impact on adjoining private property? ☒ Yes ☐ No *(Please skip to Q.33.)*
32. What is the most likely impact? ☐ Temporary inconvenience ☒ Cosmetic damage only ☐ Structural damage ☐ Destruction of property
33. Is the asset subject to exogenous damage events (e.g., vehicle crashes, extreme weather events, vandalism, etc.)? ☒ Yes ☐ No *(Please skip to Q.35.)*
34. *If Yes*, how frequently is the asset likely to be damaged? *Please check one only.* ☐ At least daily ☐ 1-6 times per week ☐ 1-3 times per month ☐ 1-11 times per year ☐ Once in 1-3 years ☐ Once in 4-10 years ☒ Less than once in 10 years

35. What do you estimate the cost of routine maintenance is as a fraction of the cost of replacement? ☒ Less than 10 percent ☐ 10-49 percent ☐ 50 percent or more
36. Who does repair, replacement, or refurbishment? ☐ DOTD staff ☐ Contractor ☒ Both
37. Will knowledge of the state of the asset impact the likelihood of obtaining state or federal funds for repair, replacement, updating, or refurbishment of the asset? ☐ Increase a lot ☒ Increase somewhat ☐ No effect ☐ Decrease somewhat ☐ Decrease a lot

Click on the button below to go to the desired worksheet

Intro-duction | Asset Charac-teristics | Existing Data | Summary of Data | Break-points

The summary of results is shown in Figure 12.

Figure 12. Summary of results for culverts and cross drains

Asset: **Culverrts and Cross Drains**

Asset Data Description		
2.	**Spatial Location:**	Required
3.	**Locations:**	Along all state and federal roadways
4.	**Required Measurements:**	Capacity and Length
5.	**Responsibility for Asset:**	DOTD in-house staff
6.	**Materials Relevant:**	Yes
7.	**What Materials:**	Pipe material itself, backfill materials, and any surface repairs to the asphalt or
8.	**Normal Life of the Asset:**	More than 40 years
9.	**Level of performance needed:**	Yes

Data Requirements		
10.	**Database exists and is not too old**	No
11.	**Located in:**	
12.	**Database in:**	
13.	**Database is too old**	No
14.	**Location of Assets Included**	Needed
3.	**Number of Locations**	Along all state and federal roadways
15.	**Relevant Size**	Needed
16.	**Relevant Materials**	Needed
17.	**Age of Asset**	Needed
18.	**State of Repair**	Needed
19.	**Visible State of Repair:**	No
20.	**Type of inspection required:**	Brief examination (<1 hour)
21.	**In-house inspection?**	Yes
22.	**Routine Inspections are carried out:**	No
23.	**Amount of Asset inspected annually:**	None
24.	**Inspection Data in dataset?**	N/A
25.	**Location of Annual Inspection Data:**	N/A
26.	**Level of Performance**	Needed
	TOTAL SCORE	123
	Cost	High

Click on the button to go to the desired worksheet

Intro-duction | Asset Charac-teristics | Existing Data | Benefits | Break-points

Database Maintenance Requirements		
3.	**Number of Locations**	Along all state and federal roadways
22.	**Routine inspections carried out**	No
24.	**Routine Inspections on Computer**	N/A
23.	**At least 10% inspected per year**	None
8.	**Asset Life**	More than 40 years
21.	**In-house Staff or Contractor**	In-house
20.	**Extent of required inspection**	Brief examination (<1 hour)
	Score	131
	Cost	Medium

Benefits		
27.	**Unexpected Failure Frequency**	1-10 times per year
28.	**Failure effect on the road**	Closure of 1 or more lanes
29.	**Length of time of road effect**	1 day to 1 month
30.	**Failure effect on traffic**	Traffic is detoured to a slower/longer route
31.	**Is private property impacted**	Yes
32.	**How much is it impacted**	Cosmetic damage only
33.	**Subject to damage:**	Yes
34.	**Expected frequency of damage:**	Less than once in 10 years
35.	**Routine maintenance:replacement cost**	Less than 10 percent
36.	**Who repairs or replaces**	Both
37.	**Change likelihood of funding**	Increase somewhat
	Score	1461
	Benefit	Medium

FINAL RESULTS	
Cost to create data set	**High**
Cost to Maintain Database	**Medium**
Estimated Benefits	**Medium**

Not surprisingly, the results show that the cost for creating the database in the first instance will be high, while the cost of maintaining the database is expected to be "Medium," and the benefits are also "Medium." Now, suppose that it was felt that having the database on culverts and cross drains would have a very positive impact on funding from state or federal sources. In that case, the answer to question 37 in Figure 11 would be changed to "Increase a Lot." However, this is not sufficient to push the benefits into the high range. However, if in addition the damage to private property is changed from "Cosmetic Only" to "Structural Damage," the benefit increases to "High." A further check of changing the answer to question 37 to "No Effect" brings the benefits back to "Medium," even with the structural damage to private property in place. Thus, in this case, it takes both of those outcomes to lift the benefits to "High."

This shows the sensitivity of the workbook to the inputs. It also shows the ability of the workbook to be used for sensitivity testing, especially where there is some question about the actual response to some questions. The scores reported in Figure 12 can also be examined against the breakpoints, shown in Figure 13. The breakpoints are the boundaries between each level of cost or benefit. The user can change these, but the distribution of the scenarios should be approximately normal, irrespective of changes in the breakpoints. In other words, the percentage of scenarios falling in the lowest and highest categories should be the smallest, while those in the next category above the lowest and below the highest should have a much larger percentage of scenarios, and the middle category should have the highest percentage of scenarios.

Figure 13. Breakpoints used in the culverts and cross drains example

Breakpoints for Assessing Costs and Benefits of Assets

Break points for Initial Cost		**Percent of Scenarios**
12	Very Low	6.4%
25	Low	16.6%
100	Medium	53.3%
131	High	17.4%
	Very High	6.3%

Breakpoints for Data Maintenance		**Percent of Scenarios**
38	Very Low	7.8%
80	Low	17.8%
160	Medium	48.9%
210	High	17.8%
	Very High	7.8%

Breakpoints for Benefits		**Percent of Scenarios**
300	Very Low	4.5%
700	Low	15.3%
3100	Medium	39.4%
4300	High	15.7%
	Very High	4.6%

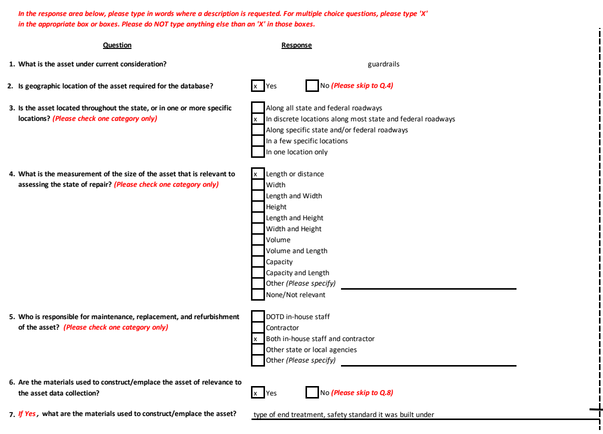
Click on the button below to go to the desired worksheet

Only the score for creation of the database lies close to a breakpoint. The score for database creation was 123, while the breakpoint between “Medium” and “High” is 100. This could suggest the possibility of checking to see the impact of revising this breakpoint to 125 to see what impact that has on the distribution of the categories. It turns out that such a change moves just two outcomes from “High” to “Medium”—a change of 1.3 percent—and does not result in a dramatic change to the distribution of outcomes. This would change the category for the culverts and cross drains to “Medium” for the creation of the database. Thus, it can be concluded that the cost of creation is on the borderline of “Medium” and “High.”

Guardrails

The second example is for guardrails (not including steel rope crash barriers). Completion of the first worksheet is shown in Figure 14.

Figure 14. Completion of the first worksheet – asset characteristics – for guardrails



In the response area below, please type in words where a description is requested. For multiple choice questions, please type 'X' in the appropriate box or boxes. Please do NOT type anything else than an 'X' in those boxes.

Question / Response

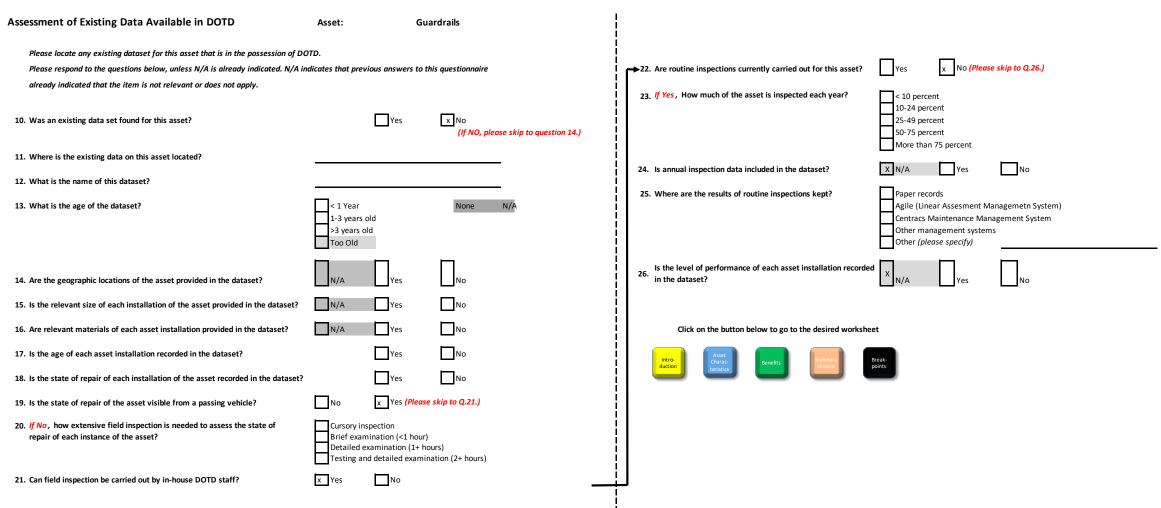
1. What is the asset under current consideration? — guardrails
2. Is geographic location of the asset required for the database? — [x] Yes [ ] No *(Please skip to Q.4)*
3. Is the asset located throughout the state, or in one or more specific locations? *(Please check one category only)* — [ ] Along all state and federal roadways; [x] In discrete locations along most state and federal roadways; [ ] Along specific state and/or federal roadways; [ ] In a few specific locations; [ ] In one location only
4. What is the measurement of the size of the asset that is relevant to assessing the state of repair? *(Please check one category only)* — [x] Length or distance; [ ] Width; [ ] Length and Width; [ ] Height; [ ] Length and Height; [ ] Width and Height; [ ] Volume; [ ] Volume and Length; [ ] Capacity; [ ] Capacity and Length; [ ] Other *(Please specify)*; [ ] None/Not relevant
5. Who is responsible for maintenance, replacement, and refurbishment of the asset? *(Please check one category only)* — [ ] DOTD in-house staff; [ ] Contractor; [x] Both in-house staff and contractor; [ ] Other state or local agencies; [ ] Other *(Please specify)*
6. Are the materials used to construct/emplace the asset of relevance to the asset data collection? — [x] Yes [ ] No *(Please skip to Q.8)*
7. *If Yes*, what are the materials used to construct/emplace the asset? — type of end treatment, safety standard it was built under
8. What is the expected normal life of the asset? — [ ] Less than 1 year; [ ] 1-3 years; [ ] 4-10 years; [ ] 11-20 years; [ ] 21-30 years; [ ] 31-40 years; [x] More than 40 years
9. Is the level of performance of the asset relevant? — [ ] Yes [x] No

Click on the button below to go to the desired worksheet

Intro-duction | Existing Data | Benefits | Summary of Data | Break-points

Completion of the second worksheet is shown in Figure 15.

Figure 15. Completion of the second worksheet – existing data – guardrails



Assessment of Existing Data Available in DOTD — Asset: Guardrails

Please locate any existing dataset for this asset that is in the possession of DOTD.
Please respond to the questions below, unless N/A is already indicated. N/A indicates that previous answers to this questionnaire already indicated that the item is not relevant or does not apply.

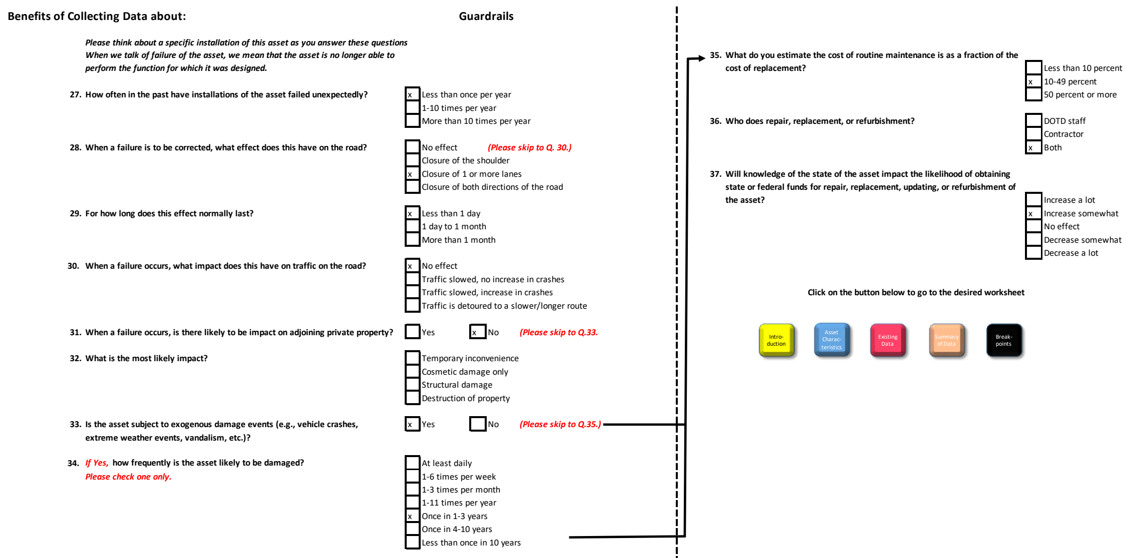
10. Was an existing data set found for this asset? — [ ] Yes [x] No *(If NO, please skip to question 14.)*
11. Where is the existing data on this asset located?
12. What is the name of this dataset?
13. What is the age of the dataset? — [ ] < 1 Year; [ ] 1-3 years old; [ ] >3 years old; [ ] Too Old — None N/A
14. Are the geographic locations of the asset provided in the dataset? — [ ] N/A [ ] Yes [ ] No
15. Is the relevant size of each installation of the asset provided in the dataset? — [ ] N/A [ ] Yes [ ] No
16. Are relevant materials of each asset installation provided in the dataset? — [ ] N/A [ ] Yes [ ] No
17. Is the age of each asset installation recorded in the dataset? — [ ] Yes [ ] No
18. Is the state of repair of each installation of the asset recorded in the dataset? — [ ] Yes [ ] No
19. Is the state of repair of the asset visible from a passing vehicle? — [ ] No [x] Yes *(Please skip to Q.21.)*
20. *If No*, how extensive field inspection is needed to assess the state of repair of each instance of the asset? — [ ] Cursory inspection; [ ] Brief examination (<1 hour); [ ] Detailed examination (1+ hours); [ ] Testing and detailed examination (2+ hours)
21. Can field inspection be carried out by in-house DOTD staff? — [x] Yes [ ] No
22. Are routine inspections currently carried out for this asset? — [ ] Yes [x] No *(Please skip to Q.26.)*
23. *If Yes*, How much of the asset is inspected each year? — [ ] < 10 percent; [ ] 10-24 percent; [ ] 25-49 percent; [ ] 50-75 percent; [ ] More than 75 percent
24. Is annual inspection data included in the dataset? — [x] N/A [ ] Yes [ ] No
25. Where are the results of routine inspections kept? — [ ] Paper records; [ ] Agile (Linear Assesment Managemetn System); [ ] Centracs Maintenance Management System; [ ] Other management systems; [ ] Other *(please specify)*
26. Is the level of performance of each asset installation recorded in the dataset? — [x] N/A [ ] Yes [ ] No

Click on the button below to go to the desired worksheet

Intro-duction | Asset Charac-teristics | Benefits | Summary of Data | Break-points

This worksheet shows that there is no existing dataset in DOTD for guardrails, and that state of repair can be assessed from a passing vehicle. Routine inspections are not currently carried out for guardrails. The third worksheet on the benefits is shown in Figure 16.

Figure 16. Completion of the third worksheet – benefits – for guardrails



The summary of the data is then provided in Figure 17, based on these three worksheets.

Figure 17. Summary of results for guardrails

Asset: Guardrails

Asset Data Description		
2.	Spatial Location:	Required
3.	Locations:	In discrete locations along most state and federal roadways
4.	Required Measurements:	Length or distance
5.	Responsibility for Asset:	Both in-house staff and contractor
6.	Materials Relevant:	Yes
7.	What Materials:	type of end treatment, safety standard it was built under
8.	Normal Life of the Asset:	More than 40 years
9.	Level of performance needed:	No

Database Maintenance Requirements		
3.	Number of Locations	In discrete locations along most state and federal roadways
22.	Routine inspections carried out	No
24.	Routine Inspections on Computer	N/A
23.	At least 10% inspected per year	None
8.	Asset Life	More than 40 years
21.	In-house Staff or Contractor	In-house
20.	Extent of required inspection	In-Vehicle
	Score	63
	Cost	Low

Data Requirements		
10.	Database exists and is not too old	No
11.	Located in:	
12.	Database in:	
13.	Database is too old	No
14.	Location of Assets Included	Needed
3.	Number of Locations	In discrete locations along most state and federal roadways
15.	Relevant Size	Needed
16.	Relevant Materials	Needed
17.	Age of Asset	Needed
18.	State of Repair	Needed
19.	Visible State of Repair:	Yes
20.	Type of inspection required:	In-vehicle
21.	In-house inspection?	Yes
22.	Routine Inspections are carried out:	No
23.	Amount of Asset inspected annually:	None
24.	Inspection Data in dataset?	N/A
25.	Location of Annual Inspection Data:	N/A
26.	Level of Performance	Not Needed
	TOTAL SCORE	56
	Cost	Medium

Benefits		
27.	Unexpected Failure Frequency	Less than once per year
28.	Failure effect on the road	Closure of 1 or more lanes
29.	Length of time of road effect	Less than 1 day
30.	Failure effect on traffic	No effect
31.	Is private property impacted	No
32.	How much is it impacted	No private property damage
33.	Subject to damage:	Yes
34.	Expected frequency of damage:	Once in 1-3 years
35.	Routine maintenance:replacement cost	10-49 percent
36.	Who repairs or replaces	Both
37.	Change likelihood of funding	Increase somewhat
	Score	902
	Benefit	Medium

FINAL RESULTS	
Cost to create data set	Medium
Cost to Maintain Database	Low
Estimated Benefits	Medium

Click on the button to go to the desired worksheet

Intro-duction | Asset Charac-teristics | Existing Data | Benefits | Break-points

In this case, the costs of creating the database are indicated as being "Medium" and the costs of maintaining the database is low. The benefits of creating the database are estimated to be "Medium." The breakpoints used are the same as the previous case and are shown in Figure 18. The score for database creation is very much in the middle of the "Medium" range and so is not susceptible to change from any reasonable change of the breakpoints. The same is true for the costs of maintaining the database, while the benefits also fall well away from the breakpoints. Hence, the results of these three estimations are considered to be robust.

Figure 18. Breakpoints used for guardrails

Breakpoints for Assessing Costs and Benefits of Assets

Break points for Initial Cost

		Percent of Scenarios
12	Very Low	6.4%
25	Low	16.6%
100	Medium	53.3%
131	High	17.4%
	Very High	6.3%

Breakpoints for Data Maintenance

		Percent of Scenarios
38	Very Low	7.8%
80	Low	17.8%
160	Medium	48.9%
210	High	17.8%
	Very High	7.8%

Breakpoints for Benefits

		Percent of Scenarios
300	Very Low	4.5%
700	Low	15.3%
3100	Medium	39.4%
4300	High	15.7%
	Very High	4.6%

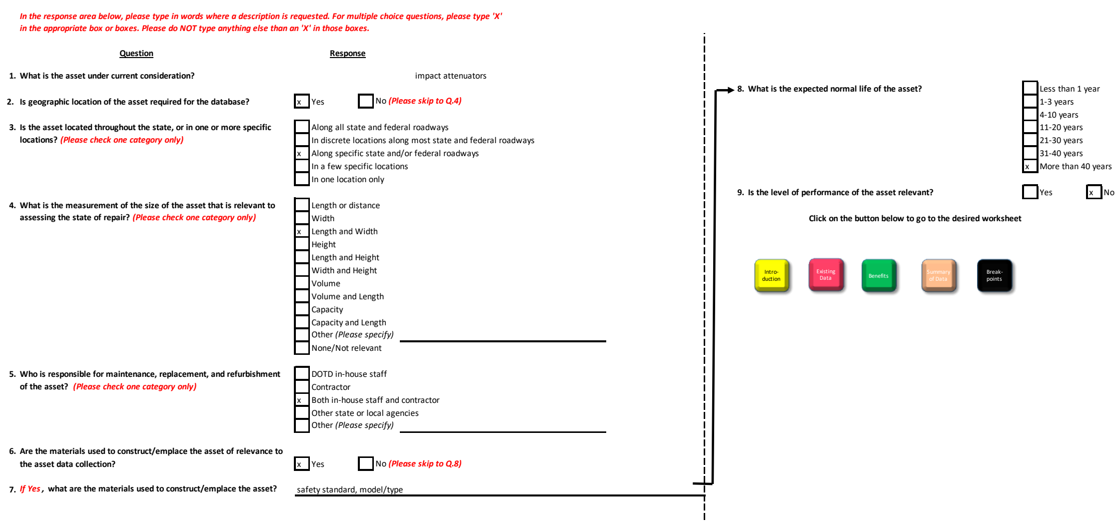
Click on the button below to go to the desired worksheet

Impact Attenuators

The third asset that was tested was that of impact attenuators. The results of the first worksheet are shown in Figure 19. Similar to the previous two assets, this is an asset with an expected long life. Figure 20 shows the results of the second worksheet for the existing data. Again, an existing database does not exist for this asset and routine inspections are not carried out for the asset. The results of the third worksheet are shown in Figure 21. The summary results and estimates of costs and benefits are shown in Figure 22. The result is similar to that for guardrails, with medium costs to establish the database, low costs for maintaining it, and medium benefits from having the database.

The breakpoints were the same for this asset as for guardrails and the scores were again not close to breakpoint boundaries, so that the results would be unlikely to change if some modification was made to the breakpoints.

Figure 19. Results of the first worksheet – asset characteristics – impact attenuators



In the response area below, please type in words where a description is requested. For multiple choice questions, please type 'X' in the appropriate box or boxes. Please do NOT type anything else than an 'X' in those boxes.

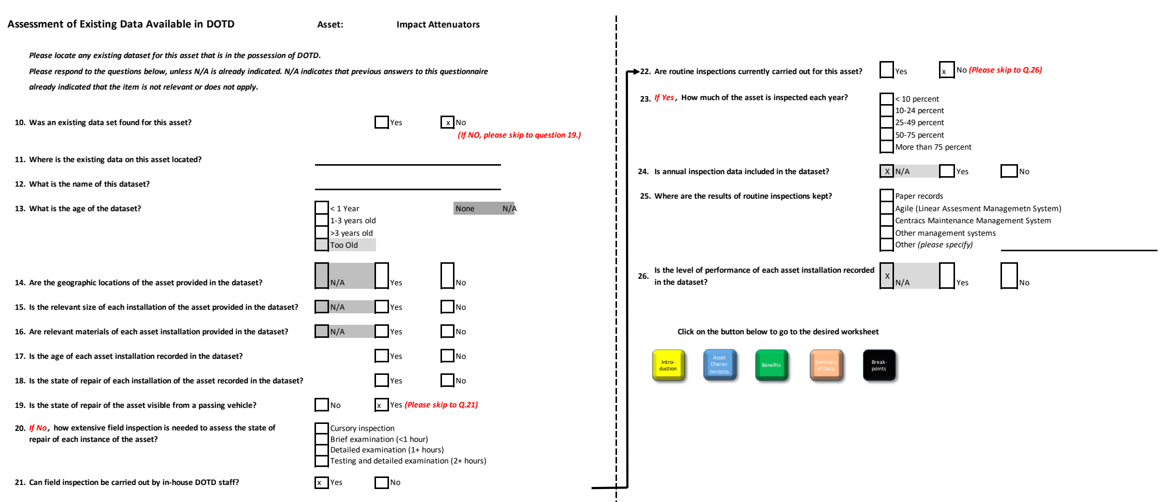
Question | **Response**

1. What is the asset under current consideration? — impact attenuators
2. Is geographic location of the asset required for the database? — x Yes / No *(Please skip to Q.4)*
3. Is the asset located throughout the state, or in one or more specific locations? *(Please check one category only)*
   - Along all state and federal roadways
   - In discrete locations along most state and federal roadways
   - x Along specific state and/or federal roadways
   - In a few specific locations
   - In one location only
4. What is the measurement of the size of the asset that is relevant to assessing the state of repair? *(Please check one category only)*
   - Length or distance
   - Width
   - x Length and Width
   - Height
   - Length and Height
   - Width and Height
   - Volume
   - Volume and Length
   - Capacity
   - Capacity and Length
   - Other *(Please specify)*
   - None/Not relevant
5. Who is responsible for maintenance, replacement, and refurbishment of the asset? *(Please check one category only)*
   - DOTD in-house staff
   - Contractor
   - x Both in-house staff and contractor
   - Other state or local agencies
   - Other *(Please specify)*
6. Are the materials used to construct/emplace the asset of relevance to the asset data collection? — x Yes / No *(Please skip to Q.8)*
7. *If Yes*, what are the materials used to construct/emplace the asset? — safety standard, model/type
8. What is the expected normal life of the asset?
   - Less than 1 year
   - 1-3 years
   - 4-10 years
   - 11-20 years
   - 21-30 years
   - 31-40 years
   - x More than 40 years
9. Is the level of performance of the asset relevant? — Yes / x No

Click on the button below to go to the desired worksheet

Intro-duction | Existing Data | Benefits | Summary of Data | Break-points

Figure 20. Completion of the second worksheet – existing data – for impact attenuators



Assessment of Existing Data Available in DOTD Asset: **Impact Attenuators**

Please locate any existing dataset for this asset that is in the possession of DOTD.
Please respond to the questions below, unless N/A is already indicated. N/A indicates that previous answers to this questionnaire already indicated that the item is not relevant or does not apply.

10. Was an existing data set found for this asset? — Yes / x No *(If NO, please skip to question 19.)*
11. Where is the existing data on this asset located?
12. What is the name of this dataset?
13. What is the age of the dataset? — < 1 Year / 1-3 years old / >3 years old / Too Old — None N/A
14. Are the geographic locations of the asset provided in the dataset? — N/A / Yes / No
15. Is the relevant size of each installation of the asset provided in the dataset? — N/A / Yes / No
16. Are relevant materials of each asset installation provided in the dataset? — N/A / Yes / No
17. Is the age of each asset installation recorded in the dataset? — Yes / No
18. Is the state of repair of each installation of the asset recorded in the dataset? — Yes / No
19. Is the state of repair of the asset visible from a passing vehicle? — No / x Yes *(Please skip to Q.21)*
20. *If No*, how extensive field inspection is needed to assess the state of repair of each instance of the asset?
    - Cursory inspection
    - Brief examination (<1 hour)
    - Detailed examination (1+ hours)
    - Testing and detailed examination (2+ hours)
21. Can field inspection be carried out by in-house DOTD staff? — x Yes / No
22. Are routine inspections currently carried out for this asset? — Yes / x No *(Please skip to Q.26)*
23. *If Yes*, How much of the asset is inspected each year?
    - < 10 percent
    - 10-24 percent
    - 25-49 percent
    - 50-75 percent
    - More than 75 percent
24. Is annual inspection data included in the dataset? — X N/A / Yes / No
25. Where are the results of routine inspections kept?
    - Paper records
    - Agile (Linear Assesment Managemetn System)
    - Centracs Maintenance Management System
    - Other management systems
    - Other *(please specify)*
26. Is the level of performance of each asset installation recorded in the dataset? — X N/A / Yes / No

Click on the button below to go to the desired worksheet

Intro-duction | Asset Charac-teristics | Benefits | Summary of Data | Break-points

Figure 21. Completion of the third worksheet – benefits – for impact attenuators

Benefits of Collecting Data about: **Impact Attenuators**

Please think about a specific installation of this asset as you answer these questions When we talk of failure of the asset, we mean that the asset is no longer able to perform the function for which it was designed.

27. How often in the past have installations of the asset failed unexpectedly?
- [ ] Less than once per year
- [x] 1-10 times per year
- [ ] More than 10 times per year

28. When a failure is to be corrected, what effect does this have on the road?
- [ ] No effect ***(Please skip to Q. 30.)***
- [ ] Closure of the shoulder
- [x] Closure of 1 or more lanes
- [ ] Closure of both directions of the road

29. For how long does this effect normally last?
- [x] Less than 1 day
- [ ] 1 day to 1 month
- [ ] More than 1 month

30. When a failure occurs, what impact does this have on traffic on the road?
- [x] No effect
- [ ] Traffic slowed, no increase in crashes
- [ ] Traffic slowed, increase in crashes
- [ ] Traffic is detoured to a slower/longer route

31. When a failure occurs, is there likely to be impact on adjoining private property?
- [ ] Yes
- [x] No ***(Please skip to Q.33.)***

32. What is the most likely impact?
- [ ] Temporary inconvenience
- [ ] Cosmetic damage only
- [ ] Structural damage
- [ ] Destruction of property

33. Is the asset subject to exogenous damage events (e.g., vehicle crashes, extreme weather events, vandalism, etc.)?
- [x] Yes
- [ ] No ***(Please skip to Q.35.)***

34. *If Yes,* how frequently is the asset likely to be damaged?
Please check one only.
- [ ] At least daily
- [ ] 1-6 times per week
- [ ] 1-3 times per month
- [x] 1-11 times per year
- [ ] Once in 1-3 years
- [ ] Once in 4-10 years
- [ ] Less than once in 10 years

35. What do you estimate the cost of routine maintenance is as a fraction of the cost of replacement?
- [ ] Less than 10 percent
- [ ] 10-49 percent
- [x] 50 percent or more

36. Who does repair, replacement, or refurbishment?
- [ ] DOTD staff
- [x] Contractor
- [ ] Both

37. Will knowledge of the state of the asset impact the likelihood of obtaining state or federal funds for repair, replacement, updating, or refurbishment of the asset?
- [ ] Increase a lot
- [x] Increase somewhat
- [ ] No effect
- [ ] Decrease somewhat
- [ ] Decrease a lot

Click on the button below to go to the desired worksheet

Intro-duction | Asset Charac-teristics | Existing Data | Summary of Data | Break-points

Figure 22. Results of the assessment for impact attenuators

Asset: **Impact Attenuators**

Asset Data Description		
2.	Spatial Location:	Required
3.	Locations:	Along specific state and/or federal roadways
4.	Required Measurements:	Length and Width
5.	Responsibility for Asset:	Both in-house staff and contractor
6.	Materials Relevant:	Yes
7.	What Materials:	safety standard, model/type
8.	Normal Life of the Asset:	More than 40 years
9.	Level of performance needed:	No

Database Maintenance Requirements		
3.	Number of Locations	Along specific state and/or federal roadways
22.	Routine inspections carried out	No
24.	Routine Inspections on Computer	N/A
23.	At least 10% inspected per year	None
8.	Asset Life	More than 40 years
21.	In-house Staff or Contractor	In-house
20.	Extent of required inspection	In-Vehicle
	Score	50
	Cost	Low

Data Requirements		
10.	Database exists and is not too old	No
11.	Located in:	
12.	Database in:	
13.	Database is too old	No
14.	Location of Assets Included	Needed
3.	Number of Locations	Along specific state and/or federal
15.	Relevant Size	Needed
16.	Relevant Materials	Needed
17.	Age of Asset	Needed
18.	State of Repair	Needed
19.	Visible State of Repair:	Yes
20.	Type of inspection required:	In-vehicle
21.	In-house inspection?	Yes
22.	Routine Inspections are carried out:	No
23.	Amount of Asset inspected annually:	None
24.	Inspection Data in dataset?	N/A
25.	Location of Annual Inspection Data:	N/A
26.	Level of Performance	Not Needed
	TOTAL SCORE	42
	Cost	Medium

Benefits		
27.	Unexpected Failure Frequency	1-10 times per year
28.	Failure effect on the road	Closure of 1 or more lanes
29.	Length of time of road effect	Less than 1 day
30.	Failure effect on traffic	No effect
31.	Is private property impacted	No
32.	How much is it impacted	No private property damage
33.	Subject to damage:	Yes
34.	Expected frequency of damage:	1-11 times per year
35.	Routine maintenance:replacement cost	50 percent or more
36.	Who repairs or replaces	Contractor
37.	Change likelihood of funding	Increase somewhat
	Score	981
	Benefit	Medium

FINAL RESULTS	
Cost to create data set	Medium
Cost to Maintain Database	Low
Estimated Benefits	Medium

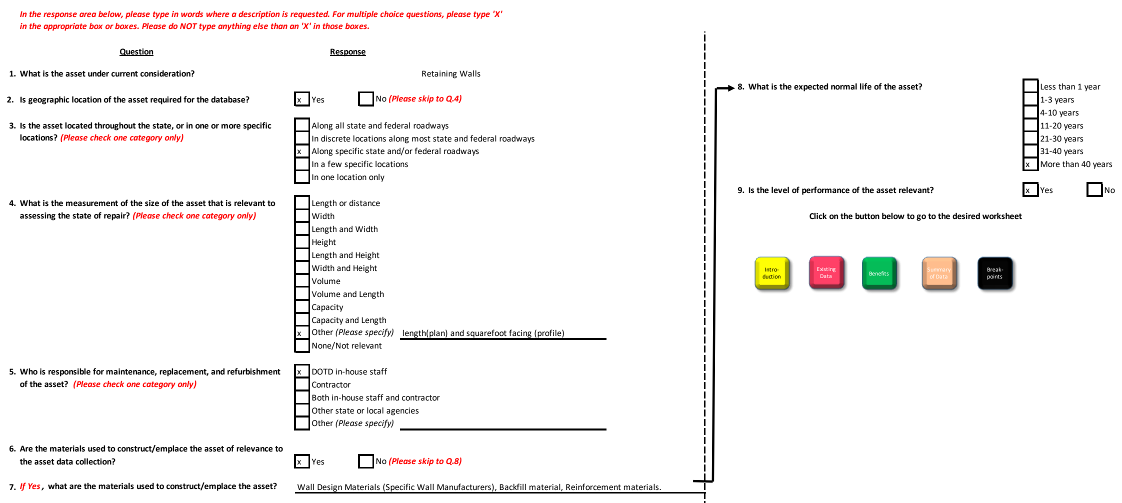
Click on the button to go to the desired worksheet

Intro-duction | Asset Charac-teristics | Existing Data | Benefits | Break-points

Retaining Walls

A fourth asset was also assessed, that of retaining walls. This is included because it is an instance where a database already exists. The completion of the first worksheet is shown in Figure 23. The second worksheet is shown in Figure 24. In this case, there is an existing dataset, and its details are provided in this worksheet. The dataset is held at LTRC, and the name of the dataset is indicated. Because there is an existing dataset, it would be expected that the cost of creating the dataset would be zero. This is seen in the summary of results.

Figure 23. Completion of first worksheet – asset characteristics – retaining walls



In the response area below, please type in words where a description is requested. For multiple choice questions, please type 'X' in the appropriate box or boxes. Please do NOT type anything else than an 'X' in those boxes.

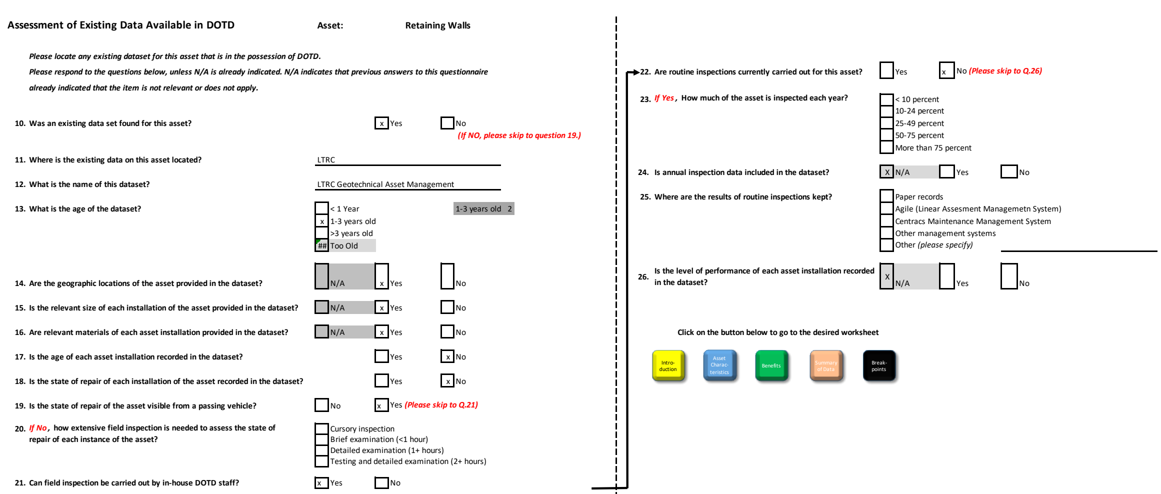
Question — **Response**

1. What is the asset under current consideration? — Retaining Walls
2. Is geographic location of the asset required for the database? — [x] Yes [ ] No *(Please skip to Q.4)*
3. Is the asset located throughout the state, or in one or more specific locations? *(Please check one category only)*
   - [ ] Along all state and federal roadways
   - [ ] In discrete locations along most state and federal roadways
   - [x] Along specific state and/or federal roadways
   - [ ] In a few specific locations
   - [ ] In one location only
4. What is the measurement of the size of the asset that is relevant to assessing the state of repair? *(Please check one category only)*
   - [ ] Length or distance
   - [ ] Width
   - [ ] Length and Width
   - [ ] Height
   - [ ] Length and Height
   - [ ] Width and Height
   - [ ] Volume
   - [ ] Volume and Length
   - [ ] Capacity
   - [ ] Capacity and Length
   - [x] Other *(Please specify)* length(plan) and squarefoot facing (profile)
   - [ ] None/Not relevant
5. Who is responsible for maintenance, replacement, and refurbishment of the asset? *(Please check one category only)*
   - [x] DOTD in-house staff
   - [ ] Contractor
   - [ ] Both in-house staff and contractor
   - [ ] Other state or local agencies
   - [ ] Other *(Please specify)*
6. Are the materials used to construct/emplace the asset of relevance to the asset data collection? — [x] Yes [ ] No *(Please skip to Q.8)*
7. *If Yes*, what are the materials used to construct/emplace the asset? — Wall Design Materials (Specific Wall Manufacturers), Backfill material, Reinforcement materials.
8. What is the expected normal life of the asset?
   - [ ] Less than 1 year
   - [ ] 1-3 years
   - [ ] 4-10 years
   - [ ] 11-20 years
   - [ ] 21-30 years
   - [ ] 31-40 years
   - [x] More than 40 years
9. Is the level of performance of the asset relevant? — [x] Yes [ ] No

Click on the button below to go to the desired worksheet

Intro-duction | Existing Data | Benefits | Summary of Data | Break-points

Figure 24. Completion of the second worksheet – existing data – for retaining walls



Assessment of Existing Data Available in DOTD — **Asset:** **Retaining Walls**

Please locate any existing dataset for this asset that is in the possession of DOTD.
Please respond to the questions below, unless N/A is already indicated. N/A indicates that previous answers to this questionnaire already indicated that the item is not relevant or does not apply.

10. Was an existing data set found for this asset? — [x] Yes [ ] No *(If NO, please skip to question 19.)*
11. Where is the existing data on this asset located? — LTRC
12. What is the name of this dataset? — LTRC Geotechnical Asset Management
13. What is the age of the dataset? — 1-3 years old 2
    - [ ] < 1 Year
    - [x] 1-3 years old
    - [ ] >3 years old
    - [##] Too Old
14. Are the geographic locations of the asset provided in the dataset? — [ ] N/A [x] Yes [ ] No
15. Is the relevant size of each installation of the asset provided in the dataset? — [ ] N/A [x] Yes [ ] No
16. Are relevant materials of each asset installation provided in the dataset? — [ ] N/A [x] Yes [ ] No
17. Is the age of each asset installation recorded in the dataset? — [ ] Yes [x] No
18. Is the state of repair of each installation of the asset recorded in the dataset? — [ ] Yes [x] No
19. Is the state of repair of the asset visible from a passing vehicle? — [ ] No [x] Yes *(Please skip to Q.21)*
20. *If No*, how extensive field inspection is needed to assess the state of repair of each instance of the asset?
    - [ ] Cursory inspection
    - [ ] Brief examination (<1 hour)
    - [ ] Detailed examination (1+ hours)
    - [ ] Testing and detailed examination (2+ hours)
21. Can field inspection be carried out by in-house DOTD staff? — [x] Yes [ ] No
22. Are routine inspections currently carried out for this asset? — [ ] Yes [x] No *(Please skip to Q.26)*
23. *If Yes*, How much of the asset is inspected each year?
    - [ ] < 10 percent
    - [ ] 10-24 percent
    - [ ] 25-49 percent
    - [ ] 50-75 percent
    - [ ] More than 75 percent
24. Is annual inspection data included in the dataset? — [X] N/A [ ] Yes [ ] No
25. Where are the results of routine inspections kept?
    - [ ] Paper records
    - [ ] Agile (Linear Assesment Managemetn System)
    - [ ] Centracs Maintenance Management System
    - [ ] Other management systems
    - [ ] Other *(please specify)*
26. Is the level of performance of each asset installation recorded in the dataset? — [X] N/A [ ] Yes [ ] No

Click on the button below to go to the desired worksheet

Intro-duction | Asset Charac-teristics | Benefits | Summary of Data | Break-points

Figure 25 shows the completion of the third worksheet on the benefits. The breakpoints were the same as for guardrails. The summary of the results is shown in Figure 26.

Figure 25. Completion of the third worksheet – benefits – for retaining walls

Benefits of Collecting Data about: **Retaining Walls**

Please think about a specific installation of this asset as you answer these questions
When we talk of failure of the asset, we mean that the asset is no longer able to perform the function for which it was designed.

27. How often in the past have installations of the asset failed unexpectedly?
- [ ] Less than once per year
- [x] 1-10 times per year
- [ ] More than 10 times per year

28. When a failure is to be corrected, what effect does this have on the road?
- [ ] No effect ***(Please skip to Q. 30.)***
- [ ] Closure of the shoulder
- [x] Closure of 1 or more lanes
- [ ] Closure of both directions of the road

29. For how long does this effect normally last?
- [ ] Less than 1 day
- [ ] 1 day to 1 month
- [x] More than 1 month

30. When a failure occurs, what impact does this have on traffic on the road?
- [ ] No effect
- [ ] Traffic slowed, no increase in crashes
- [x] Traffic slowed, increase in crashes
- [ ] Traffic is detoured to a slower/longer route

31. When a failure occurs, is there likely to be impact on adjoining private property?
- [x] Yes
- [ ] No ***(Please skip to Q.33.)***

32. What is the most likely impact?
- [ ] Temporary inconvenience
- [x] Cosmetic damage only
- [ ] Structural damage
- [ ] Destruction of property

33. Is the asset subject to exogenous damage events (e.g., vehicle crashes, extreme weather events, vandalism, etc.)?
- [x] Yes
- [ ] No ***(Please skip to Q.35.)***

34. *If Yes,* how frequently is the asset likely to be damaged?
Please check one only.
- [ ] At least daily
- [ ] 1-6 times per week
- [ ] 1-3 times per month
- [ ] 1-11 times per year
- [x] Once in 1-3 years
- [ ] Once in 4-10 years
- [ ] Less than once in 10 years

35. What do you estimate the cost of routine maintenance is as a fraction of the cost of replacement?
- [ ] Less than 10 percent
- [x] 10-49 percent
- [ ] 50 percent or more

36. Who does repair, replacement, or refurbishment?
- [x] DOTD staff
- [ ] Contractor
- [ ] Both

37. Will knowledge of the state of the asset impact the likelihood of obtaining state or federal funds for repair, replacement, updating, or refurbishment of the asset?
- [ ] Increase a lot
- [ ] Increase somewhat
- [x] No effect
- [ ] Decrease somewhat
- [ ] Decrease a lot

Click on the button below to go to the desired worksheet

Intro-duction | Asset Charac-teristics | Existing Data | Summary of Data | Break-points

Figure 26. Summary of results for retaining walls

Asset: **Retaining Walls**

Asset Data Description		
2.	Spatial Location:	Required
3.	Locations:	Along specific state and/or federal roadways
4.	Required Measurements:	Other (Please specify)
5.	Responsibility for Asset:	DOTD in-house staff
6.	Materials Relevant:	Yes
7.	What Materials:	Wall Design Materials (Specific Wall Manufacturers), Backfill material,
8.	Normal Life of the Asset:	More than 40 years
9.	Level of performance needed:	Yes

Data Requirements		
10.	Database exists and is not too old	#N/A
11.	Located in:	#N/A
12.	Database in:	#N/A
13.	Database is too old	#N/A
14.	Location of Assets Included	#N/A
3.	Number of Locations	Along specific state and/or federal
15.	Relevant Size	Available
16.	Relevant Materials	Available
17.	Age of Asset	Needed
18.	State of Repair	Needed
19.	Visible State of Repair:	Yes
20.	Type of inspection required:	In-vehicle
21.	In-house inspection?	Yes
22.	Routine Inspections are carried out:	No
23.	Amount of Asset inspected annually:	None
24.	Inspection Data in dataset?	N/A
25.	Location of Annual Inspection Data:	N/A
26.	Level of Performance	Needed
	TOTAL SCORE	#N/A
	Cost	#N/A

Click on the button to go to the desired worksheet

Intro-duction | Asset Charac-teristics | Existing Data | Benefits | Break-points

Database Maintenance Requirements		
3.	Number of Locations	Along specific state and/or federal roadways
22.	Routine inspections carried out	No
24.	Routine Inspections on Computer	N/A
23.	At least 10% inspected per year	None
8.	Asset Life	More than 40 years
21.	In-house Staff or Contractor	In-house
20.	Extent of required inspection	In-Vehicle
	Score	50
	Cost	Low

Benefits		
27.	Unexpected Failure Frequency	1-10 times per year
28.	Failure effect on the road	Closure of 1 or more lanes
29.	Length of time of road effect	More than 1 month
30.	Failure effect on traffic	Traffic slowed, increase in crashes
31.	Is private property impacted	Yes
32.	How much is it impacted	Cosmetic damage only
33.	Subject to damage:	Yes
34.	Expected frequency of damage:	Once in 1-3 years
35.	Routine maintenance:replacement cost	10-49 percent
36.	Who repairs or replaces	DOTD Staff
37.	Change likelihood of funding	No effect
	Score	1341
	Benefit	Medium

FINAL RESULTS	
Cost to create data set	#N/A
Cost to Maintain Database	Low
Estimated Benefits	Medium

In this case, the cost of creating the database is shown as “Not Applicable (N/A),” which is correct given that the database already exists. The cost of maintaining the database is estimated to be low, while the benefits of maintaining this existing database are estimated to be “Medium.” The scores for these are again well into the range of these levels of cost and benefit, so that it is unlikely that any change in the breakpoints within reason would change the outcome. As a test of sensitivity, the answer to the last question on benefits was changed to “Increase a Lot.” While this increased the benefits score substantially, the benefits are still “Medium” in this scenario. However, the score was just below the breakpoint between “Medium” and “High.” However, if the likely damage to private property increased to structural damage, then the benefits become “Very High” without any change in the breakpoints. These help to show the sensitivity of the workbook to possible changes in the responses.

Conclusions

As requested, a spreadsheet method has been created that provides a means to assess the costs and benefits of creating a database for any asset of DOTD. The method has some flexibility that can allow for the effects of uncertainty to be evaluated on the outcome of the assessment of costs and benefits.

There is a drawback to this methodology that should be recognized. First, many classes of assets are quite heterogeneous and may make it somewhat difficult to respond to some of the questions. To keep the methodology simple, it has been necessary to treat each asset as being relatively homogeneous. The heterogeneity of some assets could be handled by completing the workbook for sub-classes of the asset. For example, retaining walls could be classified into those on interstate highways, those on other major roadways—such as federal roads and the more major state roads, while a third category would be retaining walls on the remaining minor state roads.

A problem may also arise in completing the workbook for any asset that is not under the jurisdiction of a particular division of DOTD. In such cases, it would be necessary to identify one or more individuals within DOTD that may have sufficient knowledge of the asset to be able to complete the workbook.

Apart from these issues, the workbook should work well for any asset owned or managed by DOTD.

Recommendations

It is recommended that the workbook be implemented for assets that are not currently included in DOTD's asset management planning procedures. A committee of upper-level management within DOTD should then review the results and make a decision based on the assessed costs of database establishment and maintenance, and the benefits to be gained from the database as to whether or not the database should be established. It is also recommended that some assets, for which a database is already in existence and is being maintained, be assessed to determine whether the decision to collect data on those assets would be warranted by this methodology. The results of this process may possibly suggest some modifications that could be made to the procedure.

Acronyms, Abbreviations, and Symbols

Term	Description
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
ARAN	Automatic Road Analyzer
BCA	Benefit-Cost Analysis
BPR	Bureau of Public Roads
B/C Ratio	Benefit-Cost Ratio
Caltrans	California Department of Transportation
CFR	Code of Federal Regulation
CTDOT	Connecticut Department of Transportation
cm	centimeter(s)
DOT	Department of Transportation
DOTD	Department of Transportation and Development
FHWA	Federal Highway Administration
ft.	foot (feet)
HPMS	Highway Performance Monitoring System
in.	inch(es)
IRR	Internal Rate of Return
ISO	Institute of Organizational Standards
LTRC	Louisiana Transportation Research Center
lb.	pound(s)
LOS	Level of Service
m	meter(s)
MassDOT	Massachusetts Department of Transportation

Term	Description
MnDOT	Minnesota Department of Transportation
NBI	National Bridge Inventory
NCHRP	National Cooperative Highway Research Program
NPV	Net Present Value
ODOT	Ohio Department of Transportation
PMS	Pavement Management System
PV	Present Value
ROI	Return on Investment
SOGR	State of Good Repair
TAM	Transportation Asset Management
TAMP	Transportation Asset Management Plan
TIMED	Transportation Investment Model for Economic Development
VHT	Vehicle hours of travel
VMT	Vehicle miles of travel

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Appendix A

This appendix provides instructions for using the workbook that is discussed in the body of this report. The workbook consists of several locked worksheets and several hidden sheets. The hidden sheets are used by the workbook to undertake some of the calculations and look up scores. The user should never have need to see these sheets.

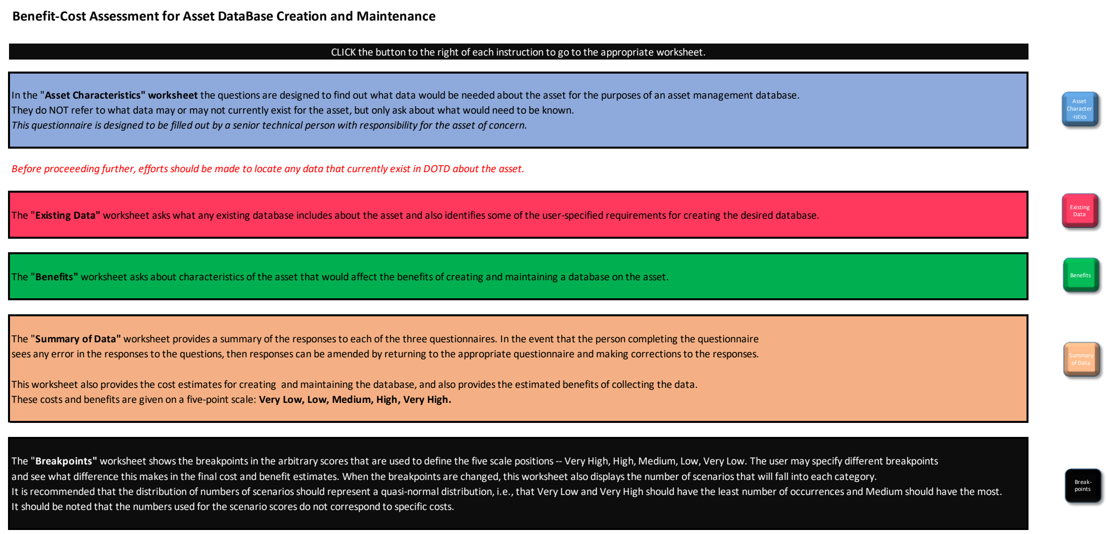
The visible worksheets are all locked and permit only entry of data into the answer spaces. Again, the user should not need ever to unlock the sheets. If any errors are encountered, first the user should check that all questions have been answered as instructed. If that is the case and the error persists, then the authors of the workbook should be contacted.

Opening Worksheet

The opening worksheet provides instructions for using the workbook. This worksheet has a yellow tab and is called “Instructions.” There is nothing for the user to fill out on this page, which is shown in Figure 27. The color of each box corresponds to the color of the tab for the worksheet that is explained within that box. It is recommended that the user read each box prior to completing the worksheet for that color. Note that the workbook should be used by a senior management person who has knowledge of the asset concerned, and that progress beyond the first worksheet to be filled out should be attempted only after searching for any existing dataset about the asset and recording information about the dataset.

Note that there is a colored button beside each block of text. Upon clicking on this button, the user will be taken to the worksheet with that color tab. Thus, clicking on the blue button labeled “Asset Characteristics,” the user will be taken to the “Asset Characteristics” worksheet and on the cell that is the first one that can be filled out. Similar buttons are to be found on each worksheet and will allow the user easily to move from one worksheet to another.

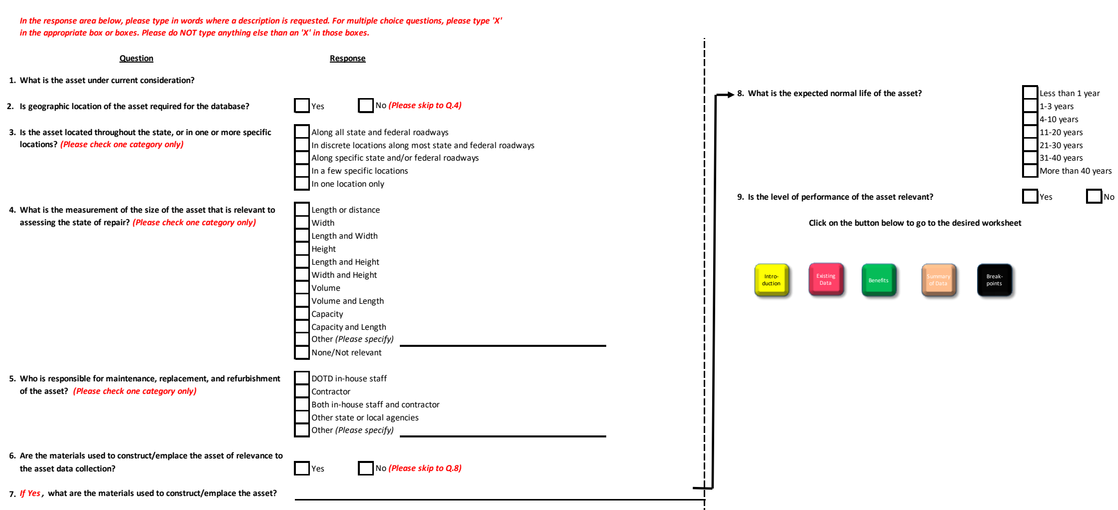
Figure 27. Opening workbook page of instructions



Second Worksheet – Asset Characteristics

The next worksheet has a blue tab and is labeled "Asset Characteristics." It is shown in Figure 28.

Figure 28. Asset characteristics worksheet



There are nine questions on this worksheet that specify the desired characteristics for the data about the asset. Instructions are shown in red and are important to follow. Question 1 asks for the name of the asset or asset class that is the subject of the completion of the workbook. This can be typed into the space provided. Unless specifically noted, only one box should be checked in the subsequent responses. It will be found that if more than one box is checked, the answer that will be used is the first one given. The layout of the worksheet has been designed so that it should display in its entirety at the right zoom level for any computer. If the entire worksheet cannot be seen, it is suggested that the zoom level be changed on the computer that is being used to display the workbook. This may need to be changed on each worksheet.

Questions 2 and 3 on this worksheet determine whether the geographic location(s) of the asset(s) is/are important to be known and, if so, how extensively the asset is located around the state. Question 4 asks about the relevant size measurements that are needed, if any. Question 5 asks who is responsible for the maintenance, refurbishment, and replacement of the asset. Question 6 asks if the materials used for the asset are relevant and, if so, question 7 asks what those materials are. Question 8 asks what the expected life of the asset is, and question 9 asks if the level of performance of the asset is relevant. That completes the first worksheet. The answers to this worksheet will be found summarized on the "Summary of Data" worksheet in the blue shaded area, and the respondent can skip to that worksheet to review the answers and make sure that all are correct. If any mistakes have been made in entering the data, the respondent can then skip back to the "Asset Characteristics" worksheet and correct those answers.

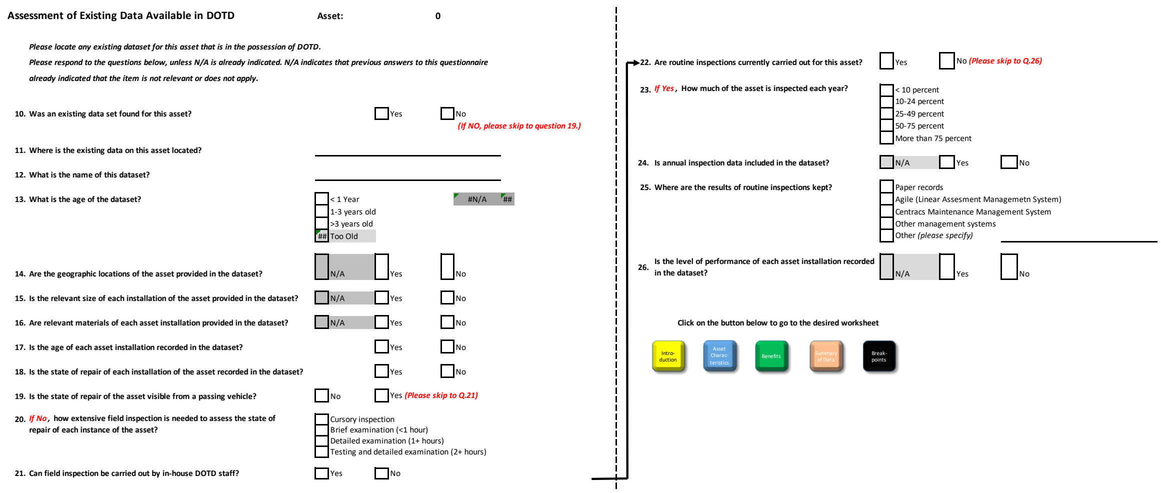
Third Worksheet – Existing Data

The next worksheet has a red tab and is labeled "Existing Data." This worksheet should not be attempted until after the user has researched whether there is an existing dataset about the asset and has obtained information about what is included in such a dataset. If no dataset has been found, then most of the questions will be irrelevant. The worksheet is shown in Figure 29.

The name of the asset is populated automatically from the previous worksheet. There are also some responses that are highlighted in grey and are automatically populated, based either on responses to this worksheet or responses to the previous worksheet.

The first question asked is whether a database was found for the asset. If it was not, the respondent should skip to question 19. Any required responses to questions 11 through 18 will be automatically populated.

Figure 29. Existing data worksheet



Assessment of Existing Data Available in DOTD   Asset: 0

Please locate any existing dataset for this asset that is in the possession of DOTD.
Please respond to the questions below, unless N/A is already indicated. N/A indicates that previous answers to this questionnaire already indicated that the item is not relevant or does not apply.

10. Was an existing data set found for this asset? ☐ Yes ☐ No *(If NO, please skip to question 19.)*
11. Where is the existing data on this asset located? ____________
12. What is the name of this dataset? ____________
13. What is the age of the dataset? ☐ < 1 Year ☐ 1-3 years old ☐ >3 years old ## Too Old   #N/A ##
14. Are the geographic locations of the asset provided in the dataset? ☐ N/A ☐ Yes ☐ No
15. Is the relevant size of each installation of the asset provided in the dataset? ☐ N/A ☐ Yes ☐ No
16. Are relevant materials of each asset installation provided in the dataset? ☐ N/A ☐ Yes ☐ No
17. Is the age of each asset installation recorded in the dataset? ☐ Yes ☐ No
18. Is the state of repair of each installation of the asset recorded in the dataset? ☐ Yes ☐ No
19. Is the state of repair of the asset visible from a passing vehicle? ☐ No ☐ Yes *(Please skip to Q.21)*
20. *If No*, how extensive field inspection is needed to assess the state of repair of each instance of the asset? ☐ Cursory inspection ☐ Brief examination (<1 hour) ☐ Detailed examination (1+ hours) ☐ Testing and detailed examination (2+ hours)
21. Can field inspection be carried out by in-house DOTD staff? ☐ Yes ☐ No
22. Are routine inspections currently carried out for this asset? ☐ Yes ☐ No *(Please skip to Q.26)*
23. *If Yes*, How much of the asset is inspected each year? ☐ < 10 percent ☐ 10-24 percent ☐ 25-49 percent ☐ 50-75 percent ☐ More than 75 percent
24. Is annual inspection data included in the dataset? ☐ N/A ☐ Yes ☐ No
25. Where are the results of routine inspections kept? ☐ Paper records ☐ Agile (Linear Assesment Managemetn System) ☐ Centracs Maintenance Management System ☐ Other management systems ☐ Other *(please specify)* ____________
26. Is the level of performance of each asset installation recorded in the dataset? ☐ N/A ☐ Yes ☐ No

Click on the button below to go to the desired worksheet

Intro-duction | Asset Charac-teristics | Benefits | Summary of Data | Break-points

If a database was found, questions 11 and 12 ask for the location of the database and the name of the database. Question 13 asks about the age of the database. If the database is too old, this is automatically generated. If the database is older than the expected life of the asset, as reported in the "Asset Characteristics" worksheet, then it will be identified as being too old.

Question 14 asks if the geographic locations of the asset are recorded in the database. If the response on the "Asset Characteristics" was that the geographic location is not necessary, then "N/A" will be automatically checked. Otherwise, the respondent should respond to this question. Question 15 asks if the relevant size of the asset is recorded in the database. Question 16 asks if relevant materials are recorded in the database. If the materials were indicated as not being relevant in the "Asset Characteristics" worksheet, then "N/A" is automatically checked. Question 17 asks if the age of the asset is recorded in the database, while question 18 asks if the current state of repair is recorded in the database. This completes the primary questions to be answered if there is a database on the asset.

Question 19 asks if the state of repair of the asset can be assessed from a passing vehicle. If it can be, the respondent should skip to question 21. If it cannot be assessed from a passing vehicle, the respondent is asked to indicate the extent of field investigation required in question 20. In question 21, the respondent indicates if this inspection (in-vehicle or other) can be done by DOTD staff or requires a consultant to undertake the inspection.

Question 22 asks if routine inspections are carried out. This is asked irrespective of whether there is an existing database on the asset. If routine inspections are not carried out, then the respondent should skip to question 26. If routine inspections are carried out, question 23 asks how much of the asset is inspected each year, in percentage terms. Question 24 asks if the inspection data are recorded in the existing database. “N/A” is automatically checked if earlier questions indicated that there is no database in existence. Question 25 asks where the records of the routine inspections are kept and offers several possible locations.

Question 26 is the last question to be asked about existing data and asks if the relevant performance level of the asset is recorded in the database. Again, if no database was found, then the answer to this question is automatically checked as “N/A.”

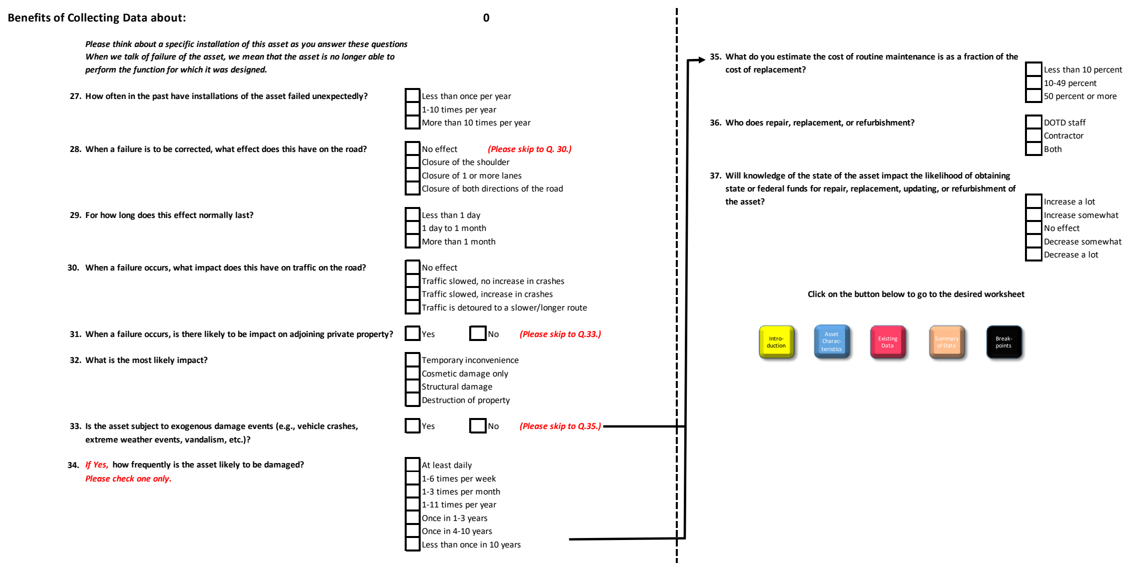
As before, the answers to these questions will be summarized in the “Summary of Data” worksheet. The respondent can skip to this worksheet to check the answers. An estimate of the costs to establish a database will also be shown at this time. If a database already exists, this will show as “#N/A,” which is correct, because no cost is involved in establishing the database in such a case. Two sections of the “Summary Data” will now be complete—the costs to establish a database and the costs of maintaining the database. The cost of the latter will also be shown on a scale from “Very Low” to “Very High.” These two areas of the “Summary of Data” are shaded in red, just as the tab of the “Existing Data” worksheet.

As for the “Asset Characteristics,” if any errors are noted in the summarized responses, the respondent has the opportunity to return to the “Existing Data” worksheet and correct any mistakes or respond to any question that was inadvertently skipped.

Fourth Worksheet – Benefits

The fourth worksheet has a green tab and is labeled “Benefits.” This worksheet is shown in Figure 30.

Figure 30. Benefits worksheet


Benefits of Collecting Data about: 0

Please think about a specific installation of this asset as you answer these questions
When we talk of failure of the asset, we mean that the asset is no longer able to perform the function for which it was designed.

27. How often in the past have installations of the asset failed unexpectedly?
- Less than once per year
- 1-10 times per year
- More than 10 times per year

28. When a failure is to be corrected, what effect does this have on the road?
- No effect *(Please skip to Q. 30.)*
- Closure of the shoulder
- Closure of 1 or more lanes
- Closure of both directions of the road

29. For how long does this effect normally last?
- Less than 1 day
- 1 day to 1 month
- More than 1 month

30. When a failure occurs, what impact does this have on traffic on the road?
- No effect
- Traffic slowed, no increase in crashes
- Traffic slowed, increase in crashes
- Traffic is detoured to a slower/longer route

31. When a failure occurs, is there likely to be impact on adjoining private property?
- Yes
- No *(Please skip to Q.33.)*

32. What is the most likely impact?
- Temporary inconvenience
- Cosmetic damage only
- Structural damage
- Destruction of property

33. Is the asset subject to exogenous damage events (e.g., vehicle crashes, extreme weather events, vandalism, etc.)?
- Yes
- No *(Please skip to Q.35.)*

34. *If Yes,* how frequently is the asset likely to be damaged?
Please check one only.
- At least daily
- 1-6 times per week
- 1-3 times per month
- 1-11 times per year
- Once in 1-3 years
- Once in 4-10 years
- Less than once in 10 years

35. What do you estimate the cost of routine maintenance is as a fraction of the cost of replacement?
- Less than 10 percent
- 10-49 percent
- 50 percent or more

36. Who does repair, replacement, or refurbishment?
- DOTD staff
- Contractor
- Both

37. Will knowledge of the state of the asset impact the likelihood of obtaining state or federal funds for repair, replacement, updating, or refurbishment of the asset?
- Increase a lot
- Increase somewhat
- No effect
- Decrease somewhat
- Decrease a lot

Click on the button below to go to the desired worksheet

To make it easier to fill out the worksheet, it is recommended that the respondent think about a specific installation of the asset in answering these questions. Question 27 asks how often unexpected failures of the asset have occurred in the past. Questions 28 through 32 relate to a failure of the asset. Question 28 asks what effect a failure has on the road. If there is no effect, then the respondent should skip to question 30. Otherwise, question 29 asks how long that effect will usually last. Question 30 then asks how much of an impact a failure is likely to have on the traffic on the road where the asset is located.

Question 31 asks if a failure will impact adjoining private property. If there is no impact, the respondent should skip to question 33. Question 32 asks what the most likely impact will be. Question 33 asks if the asset is subject to exogenous damage, such as weather, vehicular impact, vandalism, etc. that would affect the performance of the asset. If the answer is no, the respondent skips to question 35. If exogenous damage is likely to occur, question 34 asks how often this is likely to occur.

Question 35 asks about the cost of routine maintenance as a percentage of the full replacement cost, and question 36 asks who is responsible for repair, replacement, or refurbishment. The final question on this worksheet concerns whether knowledge of the state of repair is likely to impact obtaining federal or state funds for repairing or replacing the asset. This completes the "Benefits" worksheet.

Once again, the respondent can now view the “Summary of Data” worksheet which will display a summary of all the answers provided to the three worksheets. The worksheet will also show the estimated costs of establishing and maintaining a database on the asset, and what the level of benefits is likely to be. The opportunity gain exists to return to any of the preceding worksheets and correct any mistakes in the answers.

Fifth Worksheet – Summary of Data

The fifth worksheet has a buff tab and is labeled the “Summary of Data” that has been referred to several times in the preceding sections of the Appendix. It is shown in Figure 31. Nothing on this worksheet can be filled out by the respondent. This worksheet summarizes the responses to all the previous three worksheets and provides a score and an estimate of the relative costs and benefits for the asset. The name of the asset is automatically populated at the top left side of the worksheet.

The respondent should review the playback of all answers to make sure that these are as correct as possible. If any answers are considered incorrect, or subject to change, these changes can be made in the relevant worksheet. At the bottom of the left column, in the red table, the last two lines show the score and the relative cost of establishing the database. The latter of these is also picked up and shown in the table on the bottom right in buff. The parameters that affect maintenance of the database are summarized in the red box at the top of the right column. Here, the score and relative cost of maintaining the database are provided. Finally, in the green table, a summary of the responses on the benefits of having data are shown, together with a score and the relative value of the benefits.

Figure 31. Summary of data worksheet

Asset: 0

Asset Data Description		
2.	Spatial Location:	Required
3.	Locations:	#N/A
4.	Required Measurements:	#N/A
5.	Responsibility for Asset:	#N/A
6.	Materials Relevant:	Yes
7.	What Materials:	
8.	Normal Life of the Asset:	#N/A
9.	Level of performance needed:	No

Database Maintenance Requirements		
3.	Number of Locations	#N/A
22.	Routine inspections carried out	No
24.	Routine Inspections on Computer	N/A
23.	At least 10% inspected per year	#N/A
8.	Asset Life	#N/A
21.	In-house Staff or Contractor	Contractor
20.	Extent of required inspection	In-vehicle
	Score	#N/A
	Cost	#N/A

Data Requirements		
10.	Database exists and is not too old	#N/A
11.	Located in:	#N/A
12.	Database in:	#N/A
13.	Database is too old	#N/A
14.	Location of Assets Included	#N/A
3.	Number of Locations	#N/A
15.	Relevant Size	Needed
16.	Relevant Materials	Needed
17.	Age of Asset	Needed
18.	State of Repair	Needed
19.	Visible State of Repair:	No
20.	Type of inspection required:	In-vehicle
21.	In-house inspection?	No
22.	Routine Inspections are carried out:	No
23.	Amount of Asset inspected annually:	#N/A
24.	Inspection Data in dataset?	N/A
25.	Location of Annual Inspection Data:	#N/A
26.	Level of Performance	Needed
	TOTAL SCORE	#N/A
	Cost	#N/A

Benefits		
27.	Unexpected Failure Frequency	#N/A
28.	Failure effect on the road	#N/A
29.	Length of time of road effect	#N/A
30.	Failure effect on traffic	#N/A
31.	Is private property impacted	No
32.	How much is it impacted	No private property damage
33.	Subject to damage:	No
34.	Expected frequency of damage:	Not subject to damage
35.	Routine maintenance:replacement cost	#N/A
36.	Who repairs or replaces	Both
37.	Change likelihood of funding	#N/A
	Score	#N/A
	Benefit	#N/A

FINAL RESULTS	
Cost to create data set	#N/A
Cost to Maintain Database	#N/A
Estimated Benefits	#N/A

Click on the button to go to the desired worksheet

Intro-duction | Asset Charac-teristics | Existing Data | Benefits | Break-points

Sixth Worksheet – Breakpoints

As discussed in the body of the report, the respondent may make some changes to the breakpoints between the assessments of "Very Low," "Low," "Medium," "High," and "Very High." The existing breakpoints are shown in the sixth worksheet as shown in Figure 32, which has a black tab. If the scores for each of database costs, maintenance costs, and benefits are found to lie some distance from the boundaries, it is recommended that no change be made in the breakpoints. However, if any of the three scores lies very close to a boundary, then the respondent may wish to test the sensitivity of the results to small shifts in the boundaries. An example of this was provided in the body of the report. Whenever changes are made, however, every effort should be made to keep around 45 to 50 percent of scenarios in the "Medium" category, 15 to 20 percent in the "High" and "Low" categories, and the remaining 5 to 10 percent in the extremes of "Very High" and "Very Low." A radical departure from this pattern is not warranted and should be avoided.

Figure 32. Breakpoints worksheet

Breakpoints for Assessing Costs and Benefits of Assets

Break points for Initial Cost		
		Percent of Scenarios
4	Very Low	7.5%
20	Low	17.5%
92	Medium	47.5%
126	High	20.0%
	Very High	7.5%

Breakpoints for Data Maintenance		
		Percent of Scenarios
38	Very Low	7.8%
80	Low	17.8%
160	Medium	48.9%
210	High	17.8%
	Very High	7.8%

Breakpoints for Benefits		
		Percent of Scenarios
300	Very Low	5.4%
700	Low	18.4%
3100	Medium	47.2%
4300	High	18.8%
	Very High	5.5%

Click on the button below to go to the desired worksheet

After a change has been made to the breakpoints, it is of most relevance to review the "Summary of Data" worksheet. However, if there are responses to any of the other worksheets that are somewhat uncertain, changes can also be made to those answers to explore the overall sensitivity of the workbook.