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2.1 Bridge Inspection

2.1.1 Bridge Inspection Regulations

The National Bridge Inspection Program began more than 40 years ago following the collapse of the Silver Bridge over the Ohio River between West Virginia and Ohio. At that time, Congress directed the Secretary of Transportation (in cooperation with State Highway Officials) to establish:

1. National Bridge Inspection Standards (NBIS) to provide for the proper safety inspection of highway bridges, and
2. A program to train bridge inspectors to carry out the program.

As a result of this congressional direction:

1. The National Bridge Inspection Standards (NBIS) regulations were developed.
2. A bridge inspector's reference manual was prepared. (FHWA, *Bridge Inspector's Reference Manual (BIRM), 2012).*
3. A comprehensive training course, based on the reference manual, was developed.
4. The National Bridge Inventory (NBI) was established.

NBIS regulation, contained in the Code of Federal Regulations 23 CFR 650 Subpart C, sets the national standards for the safety inspection and evaluation of highway bridges. These are minimum standards and are often exceeded by more restrictive state or local standards. The NBIS apply to all highway bridges on public roads. The regulation specifies the following:

- Responsibilities of Bridge Inspection Organization
- Qualifications of personnel
- Inspection intervals
- Inspection procedures
- Bridge inventory

2.1.2 Bridge Inspection Reports and Ratings

2.1.2.1 Introduction to Bridge Inspection Reports

Bridge inspections are required on all bridges over 20 feet in total length on public roads. The Code of Federal Regulations defines the personnel qualifications, inspection types, frequencies and procedures for bridge inspection. The routine inspection report is most often used by bridge maintenance crews in their work. The bridge inspection report typically contains inspection commentary, photos, work recommendations and over 100 inventory, condition, and appraisal items. The bridge inspection report includes condition assessments reported in either NBI bridge components and general condition ratings or AASHTO bridge elements and condition states or both.

Each bridge inspection is documented with a report. The bridge inspection report can vary in format and style but generally has the following information included:

- Bridge identification and location
- Physical dimensions such as total length, span lengths, width, and clearances
- Information pertaining to the construction material and design type of the bridge
- Roadway functional classification and average daily traffic
- Safe load capacities and any load restrictions
- Channel condition and profiles
- Condition descriptions and condition ratings
- Inspection notes, sketches, and photographs
- Work recommendations
- Critical inspection findings

The inspection report is the origin of many bridge maintenance activities. An understanding of the report is essential for proper bridge maintenance.

The routine inspection is a visual inspection that is often done by inspectors on the ground and on the bridge deck. Special inspection access equipment is used as needed. The inspector is looking for damage, deterioration, or changes to the bridge since the last inspection. In many ways, these inspections are like routine physicals performed by a doctor. If the inspector observes anything that warrants further attention, follow up tests or investigation may be required. The routine bridge inspection report describes the conditions and defects observed by the inspector. The inspection report uses commentary, photographs, and condition ratings to document damage, defects or deterioration found during the inspection. The inspector may make recommendations for repairs or further analysis when necessary. Commentary and photographs in the report support the inspection findings and work recommendations.

Inspectors note the types of defect, locations, sizes, and causes of defect. The convention used to describe defect locations on the bridge can vary from one agency to the next. This convention must be understood to locate defects identified during a bridge inspection. The following is an example of conventions used to locate specific defects during an inspection:

- Spans are numbered from South to North or West to East
- Girders are numbered from left to right facing in the direction of the route
- Bays and girders are counted from left to right facing ahead on the route
- Substructure supports are numbered from South to North or West to East
- Lane numbers are assigned from left to right facing ahead on the route
- Rails are reported as left or right looking ahead on the route
- Joints are counted from the South or West abutment

Using these conventions, an inspector may note the location of a steel weld crack as follows:

"A four-inch crack was found in the span 4, girder #3, cross frame #4 stiffener to web weld approximately one inch above the top of the bottom flange." Translated, this means the crack is in span #4, in the third girder from the left at the 4^{th} cross frame in the span, and is located in the weld that connects the web stiffener to the web of the girder just above the bottom flange.

This convention is an example and may not be identical to the conventions used by all agencies. It is important to learn the nomenclature convention of your agency so that defects described in the inspection report can be located. The inspector will also record a number of general condition ratings that provide considerable information on the condition of the bridge components. The ratings determined by the inspector are based on codes established in the FHWA Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges, also known as the Coding Guide. The inspectors may also record bridge element condition states based on AASHTO manuals and other requirements of the owner agency. An example of a bridge inspection report is shown in Appendix B – References.

Other items from inspection reports that may be useful in bridge maintenance are listed below:

- Feature Intersected. The feature intersected item is what the bridge spans over. Features intersected include rivers, creeks, lakes, canyons, gullies, dry washes or other roads. For a bridge spanning over the Mississippi River the feature intersected would be reported as the Mississippi River. This item can be used in conjunction with the facility carried to locate a bridge.
- Facility Carried. The facility carried by a bridge is typically a roadway, but may also be a pedestrian facility, railroad, or utility line. For roadways, route number and milepost are reported.
- Structure Number. The structure number is a unique identification number assigned to the bridge. In most agencies the structure number is the primary identifier for all bridges.
- Location. The location field is a narrative description of where a bridge is located. For example; "6 miles Southwest of Richmond" on the roadway identified as the facility carried.
- Maintenance responsibility. The maintenance responsibility identifies the type of agency that is responsible for the maintenance of a bridge. This item is important because many bridges are owned by one agency and maintained by another under agreement. Before any maintenance is executed on a bridge, always verify that maintenance is the responsibility of your agency. Most agencies will keep maintenance agreement records for their bridges that provide additional detail on the responsibilities of a shared maintenance bridge. The most frequently used codes are; 01 – State Highway Agency, 02 - County Highway Agency, 04 – City or Municipal Highway Agency and 27 – Railroad. In total 23 different agencies are defined in the NBI. Refer to the Coding Guide for a complete listing.
- Open, Posted or Closed. This item indicates any operational restriction of the bridge. Typical operational restrictions include load, speed or lane restrictions. NBI codes of B, K, P or R indicate the need for posting signs (including closure) at both approaches to the bridge.
- Table 2.1. The inspector assigns a rating of 0 (low) to 9 (high) or N (no channel under the bridge). This NBI item can be used to evaluate channels that may need maintenance

work on channel or embankment protection devices such as riprap, gabions and spur dikes. Most channel maintenance activities will occur when channel ratings are between 3 and 7.

Table 2.1 Channel and Channel Protection Rating

Channel Rating	Generalized Condition
8,9	Good Condition
6,7	Fair Condition, Minor damage or bank slumping, Minor amounts of debris in channel
5	Poor Condition, Major damage or restriction, Trees or brush restrict channel
1,2,3,4	Severe Condition or closed to traffic
N	No channel under the bridge

- Operating Rating. The operating rating for a bridge is the maximum load (tons) that a bridge can safely carry. This rating is based on a truck and trailer combination with specific axle weights and spacing as defined by the AASHTO HL-93 truck (an example of which is shown in Figure 2.1 below, where 1 kip equals 1 thousand pounds). Note that the HL-93 truck is not a new design, but is the old HS20-44 design with added lane load. Higher numbers correspond with greater load capacity of the bridge. Consult a qualified engineer before making decisions based solely on this rating.

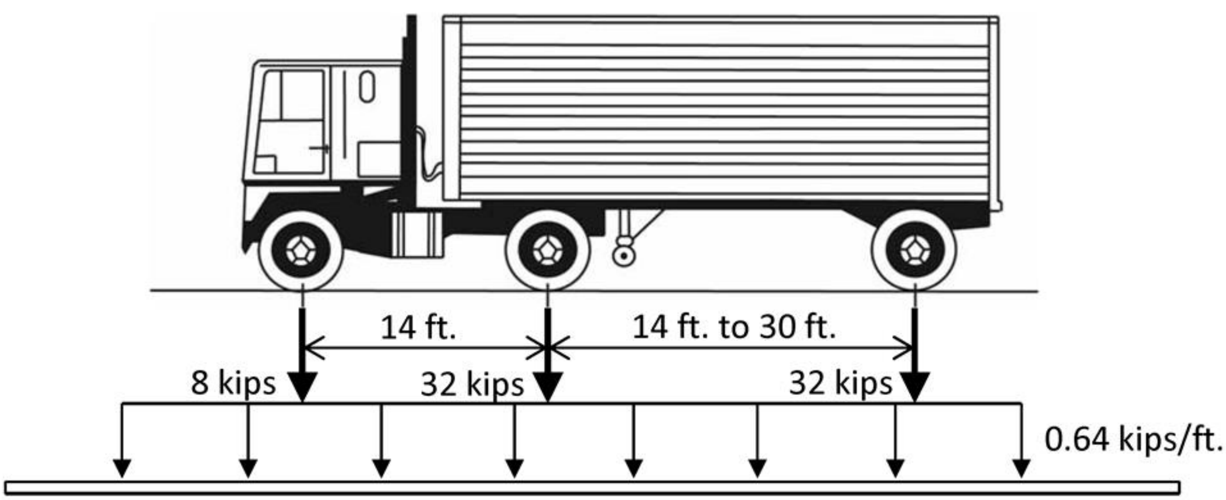

Figure 2.1 AASHTO HL-93 Truck Loading

- Scour Critical Bridges. The scour vulnerability of a bridge is reported in a bridge inspection report. Scour is the erosion of material at the bridge foundation by flowing water. Scour potential may be based on field conditions or analysis. Bridge maintenance crews should be familiar with all bridges that have scour critical codes of 4 or lower and U (where U is unknown), because these bridges require close monitoring during and immediately after periods of high stream flows. The maintenance crews should be attentive to any change in the line or grade of the bridge railings and deck, buildup of debris at substructure elements and lateral migration of the channel. All bridges with NBI codes of 3, 2, 1 or U are required to have written scour "Plans of Action" to define specific actions that are required to ensure the safety of the public during periods of high stream flows.

2.1.2.2 National Bridge Inspection General Condition Ratings

NBI general condition ratings are assessed for the Deck, Superstructure, Substructure, and Culvert. These items are all assessed based on a 0 (low) to 9 (high) rating system defined in *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*, Report Number FHWA-PD-96-0001. The reported ratings represent the overall condition of the component. Localized defects have varying impact on these ratings depending on the condition of the remainder of the component. Table 2.2 can be used an aid in understanding the NBI condition ratings.

Table 2.2 Generalized NBI Condition Ratings

NBI Rating	Description	Commonly Employed Feasible Actions
9	Excellent Condition	Preventive Maintenance
8	Very Good Condition	Preventive Maintenance
7	Good Condition	Preventive Maintenance
6	Satisfactory Condition	Preventive Maintenance/ Repairs
5	Fair Condition	Preventive Maintenance/ Repairs/ Rehabilitation
4	Poor Condition	Rehabilitation or Replacement
3	Serious	Rehabilitation or Replacement
2	Critical	Rehabilitation or Replacement
1	Immediate Failure	Rehabilitation or Replacement
0	Closed	Rehabilitation or Replacement

2.1.2.3 Element Inspection Condition Ratings

Element-level condition states and quantities are often included in the bridge inspection report. Element-level data include total quantity of each element on the bridge and a breakdown of the quantity of the each element that exists in one of four condition states. The units for quantities are EACH, FEET, and SQUARE FEET. Element numbers and their measurement units are provided in Table 2.3 and Table 2.4. See the *AASHTO Manual for Bridge Element Inspection* for a full listing of the elements and their descriptions.

Table 2.3 Frequently Used AASHTO Bridge Elements

Element	Units	Reinforced Concrete Element Numbers	Prestressed Concrete Element Numbers	Steel / Metal Elements	Timber Elements
Decks	Square Feet	12	13	28 (open)	31
Slabs	Square Feet	38	-	-	54
Rails	Feet	331	-	330	332
Box Girders	Feet	105	104	102	-
Open Girders	Feet	110	109	107	111
Truss	Feet	-	-	120	135
Stringers	Feet	116	115	113	117
Floor Beams	Feet	155	154	152	156
Columns	Each	205	204	202	206
Pier Caps	Feet	234	233	231	235
Abutments	Feet	215	-	219	216
Culverts	Feet	241	245	240	242
Pier Walls	Feet	210	-	-	212
Piles	Each	227	226	225	228

Other AASHTO elements are shown below in Table 2.4.

Table 2.4 Additional Common AASHTO Elements

Element Number	Units	Description
300	Feet	Strip seal expansion joint
301	Feet	Pourable joint seal
302	Feet	Compression joint seal
303	Feet	Assembly joint seal
305	Feet	Assembly joint without seal (Finger or similar)
310 - 316	Each	Bearings
320	Square Feet	Prestressed concrete approach slab
321	Square Feet	Reinforced concrete approach slab
510	Square Feet	Wearing surface
515	Square Feet	Steel protective coating (paint, galvanizing, etc.)
520	Square Feet	Deck protective systems (rebar coatings, cathodic protection
521	Square Feet	Concrete protective coating (Sealers, water proofing, etc.)

Element inspection condition assessments differ from the NBI component condition data in two significant ways.

- The inspection is conducted for each element independent of all others.
- The total quantity of the element is defined, and the portion of the total quantity that exists in each of four defined condition states is reported.

Every element has four condition states that have specific defect criteria as defined in the AASHTO Bridge Element Inspection Manual. Although the defect language that defines each of the four condition states varies by material and element, the following generalized condition state descriptions shown in Table 2.5 are valid:

Table 2.5 General Element Inspection Condition Descriptions

Condition State	Description	Commonly Employed Feasible Actions
1	Good	Preventive Maintenance
2	Fair	Preventive Maintenance or Repairs
3	Poor	Rehabilitation
4	Severe	Rehabilitation/Replacement

Elements can have portions of total quantity that exist in one or all four of the defined condition states.

In Table 2.6, the one square foot spall with exposed rebar is in condition state 3 because of the exposed rebar. The remainder of the 100 square feet deck element is in good condition, so 99 square feet of the element are in condition state 1.

Table 2.6 Deck Element Inspection Example

Element # - Description	Total Quantity	State 1 Quantity	State 2 Quantity	State 3 Quantity	State 4 Quantity
12 - Reinforced Concrete Deck	100 Square Feet	99 Square Feet	0	1 Square Foot	0

Now consider an example of a complete bridge, shown in Table 2.7. The element presentation is for a 50 foot long two-span reinforced concrete slab bridge with a reinforced concrete pier wall and abutments on 5 steel piles each. This bridge is 25 feet wide and has reinforced concrete rails and pourable joints at each end. The bridge is in good condition except for the failed joint seal at abutment 1.

Table 2.7 Example of a Bridge Element Model

Element	Total Quantity	State 1	State 2	State 3	State 4
38 - Reinforced Concrete Slab	50 feet x 25 feet = 1,250 square feet	1,250			
210 – Reinforced Concrete Pier Wall	1 wall x 25 feet = 25 feet	25			
215 – Reinforced Concrete Abutment	2 Abuts x 25 feet = 50 feet	50			
225 – Steel Piles	3 Supports x 5 piles = 15 each	15			
301 – Pourable Joint Seal	2 ends x 25 feet = 50 feet	25			25
331 - Reinforced Concrete Rails	2 sides x 50 feet = 100 feet	100			

2.1.2.4 Comparison of Condition Ratings

To illustrate the differences between the two bridge condition reporting systems, let's look at an example of what a condition assessment for a single bridge looks like using each system.

In this example, we have a 100 foot long, three-span, steel five-girder bridge supported on elastomeric bearings sitting on two reinforced concrete pier walls and two reinforced concrete abutments. Each substructure element is on six steel H-piles. The bridge has a 30 foot wide reinforced concrete bridge deck with an asphalt overlay that has 1/8 inch wide cracking. We have a two square foot spall in the deck with exposed rebar. The railings are steel, and all joints are compression type. The condition assessment found that all the paint on the girders has dull chalking, and a five foot length of each girder on either side of the pier joints has minor section loss from water leaking through the failed joints above. All other elements are in good condition.

Let's first consider the road surface components presented in Table 2.8:

Table 2.8 Element Inspection Condition Ratings for Road Surface Component Example

Element	Total Quantity	State 1	State 2	State 3	State 4
Reinforced Concrete Deck	100 feet x 30 feet = 3,000 square feet	2,998		2	
Wearing Surface	100 feet x 30 feet = 3,000 square feet			2,998	2
Compression Joint Seal	4 supports x 30 feet = 120 feet	60			60
Metal Rails	2 sides x 100 feet = 200 feet	200			

Using the NBI condition ratings, the inspector is to report the condition rating for the overall condition of the deck ignoring the condition of the wearing surface, joints and rails. Using the NBI condition rating system, the only defect to be considered in this example is the 2 square foot spall. The overall rating of the deck would be rated 7 (with a 9 being excellent condition).

Now let's look at the superstructure ratings (see Table 2.9):

Table 2.9 Element Inspection Superstructure Condition Ratings

Element	Total Quantity	State 1	State 2	State 3	State 4
Steel Girder	100 feet x 5 lines = 500 feet	400		100	
Protective Coating	500 feet x 8 square feet per foot = 4,000 square feet		3,200		800

Using the NBI protocol, the inspector is to report the condition rating for the overall condition of the superstructure ignoring the condition of the paint system. Using the NBI condition rating system, the only defect to be considered in this example is the minor section loss in the girders. The overall condition of the superstructure would be rated a 5 or 6.

A similar comparison of the substructure would further illustrate that the two systems capture condition in very different ways. The AASHTO element inspection is more detailed and includes condition states for joints, rails, wearing surfaces and paint systems that are not captured in the NBI component ratings. The example shown was not exhaustive, and limited to comparing the deck and superstructure for the purposes of illustrating the differences in the two rating systems

2.2 Management Systems

Many State DOTs use computerized systems to manage their bridges, pavements and maintenance programs; each of these three management systems is supported by an inspection program. In some agencies, the bridge management system (BMS) and pavement management system (PMS) interface directly with the maintenance management system (MMS).

Maintenance and repair needs of bridges are managed partly in the BMS and partly in the MMS. The following sections provide an overview of these two systems.

2.2.1 Bridge Management Systems (BMS)

2.2.1.1 Introduction to BMS

In Section 2.1, we described the types of information captured during a bridge inspection. A typical bridge inspection will generate well over 100 items of inspection related data. The bridge inspection data include: inventory information, condition assessments, inspection commentary, work recommendations and photographs and sketches. A small agency responsible for 100 bridges needs to manage over 10,000 pieces of bridge inspection data. To aid in the management of this information, many DOTs use bridge management software specifically designed for this purpose. Bridge management system (BMS) software applications are commercially available or can be custom developed to meet the needs of an agency. AASHTO develops and maintains a bridge management system software program called AASHTOWARE “Bridge Management” (formerly Pontis) that is used by the majority of state DOTs in the United States. BMS software applications have a number of features beyond just the collection and storage of inspection information. The following listing highlights some of the more common BMS features:

- Bridge inspection data storage
- Work recommendation storage
- Photographs and document storage
- Report generation
- Data mapping features
- Work prioritization calculations and rankings
- Project tracking information
- Deterioration modeling
- Definition of bridge actions and costs
- Economic decision making analysis and tools
- Bridge funding program information
- Performance measure calculations

These features support the bridge inspection program, bridge project tracking, economic analysis of potential bridge actions and performance reporting, as shown in the flow chart in Figure 2.2:

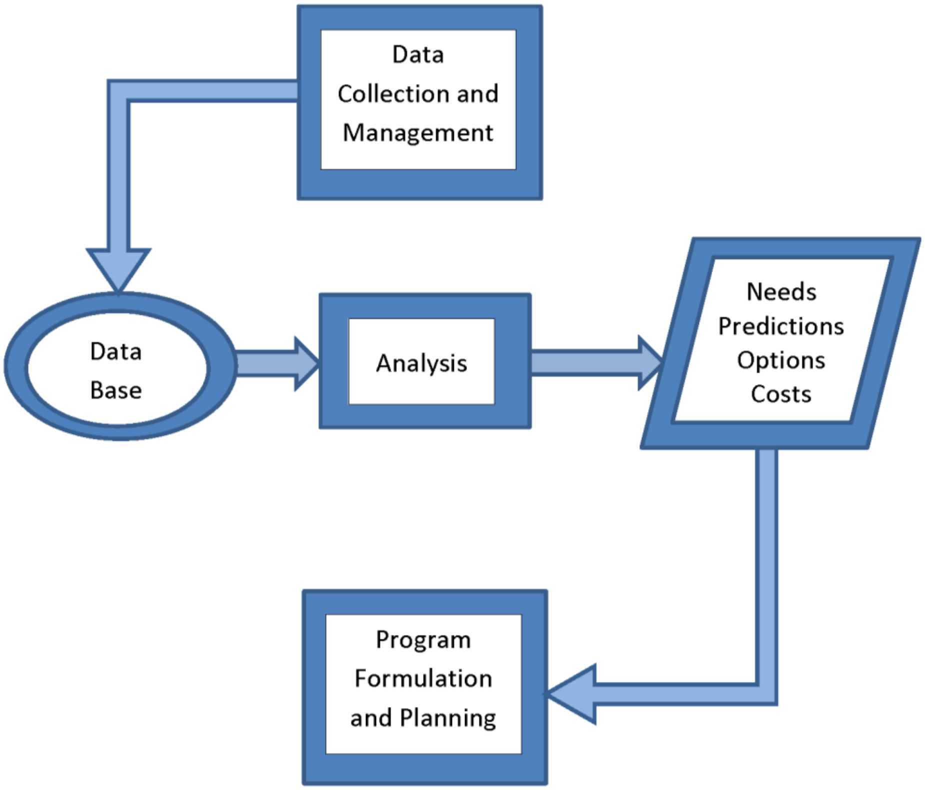

Figure 2.2 Bridge Management System Flow Chart

Bridge management systems support the inspection programs by providing a series of software screens that guide the inspector in the collection of required data. The presentation of the bridge inspection information varies among BMSs, but all should conform to federal bridge inspection requirements. Screen captures presented in Figure 2.3 and Figure 2.4 show examples of BMS bridge inspection software screens.

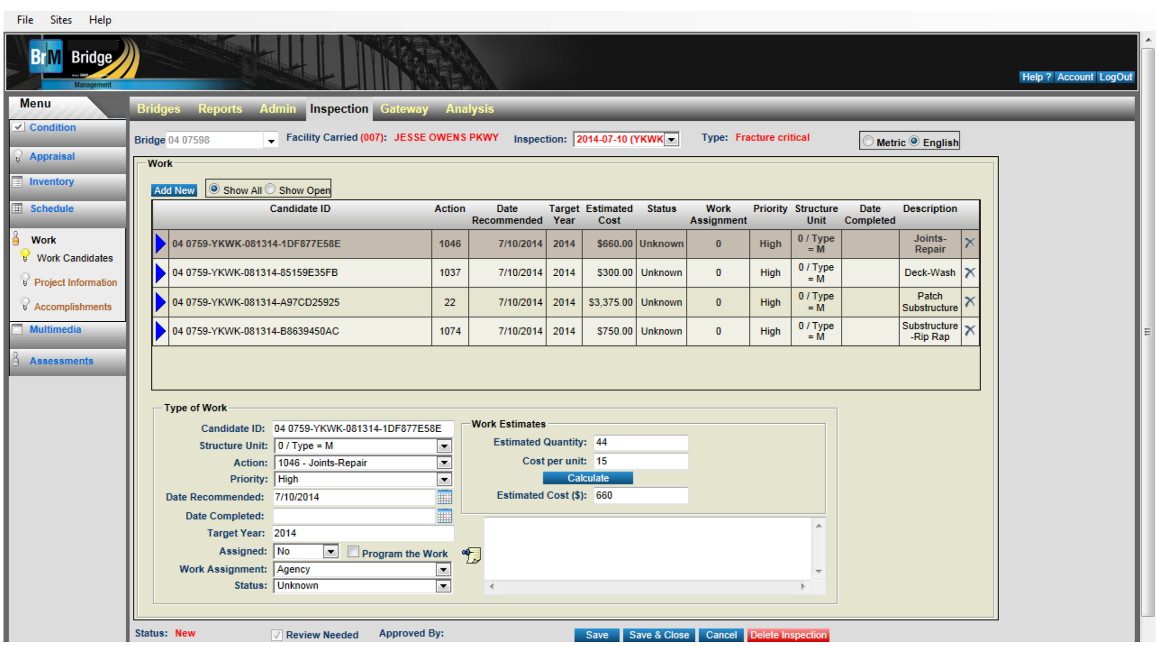

Figure 2.3 Screen Capture Example 1 of BMS Software (Courtesy of AASHTO)

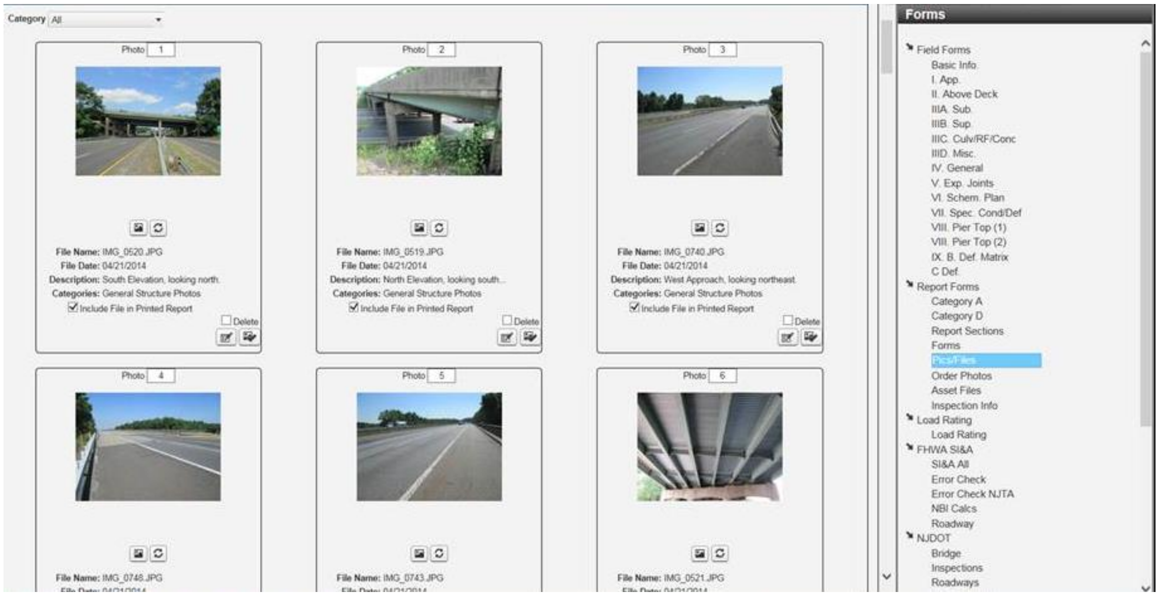

Figure 2.4 Screen Capture Example 2 of BMS Software - Courtesy of Bentley (InspectTech)

The bridge inspection and inventory data defines the bridge, its current condition and any inspector-identified work recommendations. The BMS is designed to generate many standard reports. The following reports can be generated by most BMSs:

- Bridge inspection report
- Various condition breakdowns
- Inventory listings
- Distribution of bridge age
- Material and design type breakdowns
- Ad-hoc listings of bridges meeting specified criteria
- Network element quantities
- Performance measure reports

2.2.1.2 Tracking, Identifying and Prioritizing Actions

The BMS typically stores and tracks bridge project information. The project information captured often includes the following items:

- Project description
- Project cost
- Funding sources
- Project schedule and milestones
- Bridges included in the project
- Inspector work recommendations included from each bridge in the project
- Benefit-cost evaluation for the project

Most agencies managing bridges find that the needs often exceed the funds available to fix the bridges. In these cases, the agencies must prioritize needs to find cost effective activities to undertake in a funding year. The process of analysing existing and future bridge conditions to determine the most cost effective actions is called "optimization." In most BMSs, the optimization seeks to maximize a measured benefit relative to the cost of achieving the benefit. This is a benefit-cost ratio.

PROJECT BENEFITS / PROJECT COSTS = Benefit-cost ratio or B/C ratio

The benefit of taking a particular action is a function of the current condition of the bridge and the effectiveness of the action. For example, if we were considering repainting a bridge girder, we would look at the current condition of the paint to evaluate if there would be any benefit in repainting. If the paint was exhibiting isolated areas of distress, the benefit of spot painting to repair the distressed areas would be slightly less than repainting, but at a significantly lower cost. On the other hand, if the paint was allowed to fail, then the benefit of repainting would be significant but the cost of total removal of the paint system, repair of corrosion, and completely repainting would also be significant. The benefits of the spot painting option would be slightly less than the benefits of a new paint system, but the costs, on the other hand would be significantly different. Since the cost of preparing and painting the failed system would be much higher than painting over a paint system that has only minor deterioration, the resulting benefit-cost ratio of spot painting the paint system with minor deterioration would be significantly higher. In general, an economic optimization seeks to minimize cost while maintaining some established condition threshold or maximizing benefit for a defined budget. A BMS may perform tens of thousands of benefit-cost calculations to select cost effective projects to be funded in a single year.

BMSs can perform benefit / cost calculations in the current year, and BMSs can use deterioration models to predict the condition of bridge elements in future years. Deterioration models in BMSs estimate the number of years it will take for an element to deteriorate from one condition state to the next. Element environments are also defined so that BMSs will apply an appropriate deterioration model.

Recent advances in bridge management systems incorporate bridge vulnerabilities, such as scour and seismic risks, into prioritization. Condition deterioration and risk are combined using utility functions. In a model that uses utility theory, the benefit of an action is measured in utility gain. By comparing utility benefit to cost ratios, state-of-the-art bridge management systems can optimize all bridge needs.

2.2.2 Maintenance Management Systems (MMS)

The purpose of a maintenance management system (MMS) is to plan, program, identify required resources, schedule, monitor, document, and support maintenance activities. Maintenance management systems cover many assets found on the highway system. Assets found in the MMS vary from agency to agency but often include the following:

- Drainage features (e.g., culverts, curb and gutter)
- Roadside features (e.g., fences, brush, mowing)
- Pavement features (e.g., markings)
- Structures (e.g., bridges, overhead sign structures)
- Traffic items (e.g., signs, signals)
- Lighting

- Guardrail and attenuators

Maintenance management systems take the needs identified through inspection activities and other sources and utilize information in the system to help assign to a crew, develop a work plan, assign staff, schedule work activities, track material usage, and manage equipment.

As stated in Section 2.2, maintenance and repair needs of bridges are managed partly in the BMS and partly in the MMS. Both systems typically have an inventory of the bridges, but the BMS will have significantly more information required for the NBIS. Generally, bridge work requiring engineering design is selected, optimized and tracked in the BMS, while work requiring no engineering design is scheduled and tracked in the MMS. Reporting of completed work in the MMS is also required to be reflected in the BMS for proper management.

All non-contract maintenance needs, regardless of origin or asset, must be assigned to a crew that is going to carry out the activity. Priorities for crews are dynamic and are influenced by accidents or urgent safety repair needs. For routine bridge maintenance work, the crew supervisor must take the need identified by the bridge inspector and transform it into a specific work activity for the crew. This transformation from raw need to specific work activity involves a number of steps.

2.2.2.1 Planning

Planning may be the most important function of a bridge maintenance supervisor. The MMS helps in maintenance planning. MMSs help to achieve:

- Higher production rates on projects
- Limited “down time” in-between projects
- More efficient use of “down time” for training and yard clean up
- Improvement of the condition of the bridge inventory

Planning is the prioritization of specific bridges and maintenance activities to be completed. Of all the management functions, planning is the one function that has the greatest effect on use of labor, equipment, and materials. Supervisors should consider the whole bridge system and the bridge maintenance needs over an extended period of time. Planning begins by analyzing bridge needs and the actions and resources required for the network. Once the work plan is developed and budgeted, the plan is the basis from which specific work orders are developed, scheduled, and accomplished.

2.2.2.2 Budgeting

Budgeting is the process to quantify the funds and resources needed for work plans. Maintenance activities are budgeted by aggregate categories rather than specific work activities because the activities are each relatively small. Common budgeting categories include:

- Employee costs
- Equipment costs
- Material costs
- Training costs
- Contract costs
- Engineering costs

Cost estimates are prepared when developing budgets. The work plans developed in the planning process indicate the magnitude of work required. Past expenditures and staffing are often used to estimate budgets. It is common to have maintenance needs with costs that exceed the available budget, which is why priorities among needs are determined.

2.2.2.3 Scheduling

Scheduling is the process of laying out future work. A good scheduling process develops work schedules on at least three levels:

- Organizational level
- Supervisory level
- Crew level

Scheduling is a tool to help achieve the project objectives without exceeding the budget.

Scheduling accounts for all resources: labor, equipment, and material. Schedules are more detailed at the crew level than at the organizational level. The worker's schedules are the final approved and budgeted work plans. The crew leaders schedules are very specific as to the location, date, time, and crew members assigned to a repair. Since emergency work is always a possibility, schedules must also be flexible. Emergency conditions should be met without undue strain on the organization.

2.3 Bridge Maintenance Planning

The key to the successful execution of any bridge maintenance project is the proper planning and scheduling of the work. A relatively brief amount of time spent doing quality planning will have a positive impact on performance and will create overall time savings The planning and scheduling must be done prior to beginning the project and continue during the execution.

2.3.1 Long-Term Planning

2.3.1.1 Introduction to Long-Term Planning

Long-term planning for bridge maintenance is typically 3 to 5 years, but could be longer.

The dynamic nature of bridge maintenance needs requires that longer term plans remain flexible to adapt to unidentified urgent needs that may require the crew’s attention. The continual identification of new bridge needs often necessitates that longer term planning be based on historical expenditure information to determine future budget and staffing needs.

Long-term planning involves the following steps:

- Needs are identified for all the bridges that are included.
- Preliminary cost estimates are developed, and a budget is prepared. After the budget is approved, a more detailed estimate is developed to determine the manpower and resource requirements to accomplish the work, and this is compared to the available manpower and resources.
- A decision is made to contract out the work or assign it to in house crews. This decision may be based on available staff and workload or on the need for special equipment or skills.

Priorities for work drive long-term schedules:

- The urgency of the work
- The year the work can best be performed
- When approvals or permits can be obtained
- When necessary support, equipment, and materials are available

Realistic scheduling improves efficiency. Workers should be challenged. However, if too little time is allotted to a job, shortcuts and omissions may undermine the quality of the repair work. The long-term planning effort provides general guidance regarding what to do, when to do it, and what it will take to get it done.

Once the long term planning has identified a set of work activities to be performed by the bridge maintenance crews, more detailed planning and scheduling can begin. The details of what exactly is to be done, who will do it, and what equipment and materials it will take to get the work done are included in a work order.

2.3.1.2 Work Orders

Work orders are prepared in advance and provide details of each job. The work order contains a description of the particular type of work to be performed, the exact location of the work, the names of all workers assigned to the project, and the list of equipment and materials needed to do the work. The work order may be generated in response to needs identified in a bridge inspection report, identified during other maintenance activities or through public request. At each level, long term planning, work orders, and job planning, the plan for execution of the project becomes more detailed and refined, in order to develop a plan that can be as realistic as possible about the time and resources required. The long term planning level would determine order of magnitude budget and staff requirements, Work order level is more specific in determining workers, equipment and materials, where job planning would fill in the details of how the work is actually being performed.

2.3.1.3 Job Planning

The crew leader (or a bridge maintenance engineer) usually prepares a job plan after the job is assigned to the crew. The crew leader visits the bridge and determines detailed work requirements. Factors that must be considered include:

- Traffic control and available closure windows
- Worker safety
- Environmental considerations
- How the work will be performed
- Equipment and material requirements
- Specific job assignments for crew members

A job plan is needed for every project to prevent delays.
Performance standards, if available, can be compared to the work needed. If performance standards are applicable, standards can be used to help determine the resource requirements of the job with modifications if necessary.

Performance standards define the typical time it takes for someone to perform a particular task in accordance with the agencies defined procedure. For example, a single bridge painter might be expected to prepare and paint 10,000 square feet of steel per year. If 50,000 square feet of steel needed painting, the number of crew members required to get the job done in one year could be determined (50,000 square feet/10,000 square feet per crew member = 5 crew members).

If performance standards are not available, a written description of the work to be performed should be prepared. A simple outline listing the items and order of work is sufficient. This outline of work items can be used to determine labor, material, equipment needs and to determine the time required to accomplish the repair.

2.3.1.4 Traffic Control

Any project that will place workers or equipment on or adjacent to the roadway requires traffic control in conformance with standard uniform practices. This includes correct use and placement of signs, flaggers, and delineation devices such as cones, barrels, or barricades. Most agencies have standard traffic control plans for typical situations such as shoulder and lane closures. More complex work locations may require site specific traffic control plans. The Manual for Uniform Traffic Control Devices (MUTCD) is a free publication from the Federal Highway Administration that shows proper traffic control procedures. The MUTCD contains closure plans, recommended signage and other controls for street, highway, bicycle and pedestrian traffic control.

Working on or near the highway always involves risks of vehicular accidents. Adequate traffic control is important for the crew's protection. Neglect of traffic control puts workers in harm's way and exposes the agency to very costly liability judgments.

2.3.1.5 Environmental Considerations. Permits.

Proper planning should provide adequate time to secure any necessary permits and plan for worker protection and disposal of hazardous materials. The bridge maintenance crew leader should consult with available environmental units in their organization before undertaking maintenance activities that involve asbestos, lead-based paints, toxic chemicals/materials, significant excavations or activities that require employees or equipment to be in waterways.

2.3.1.6 Worker Safety

Worker safety begins with a well thought out plan that includes ways to eliminate or mitigate hazards, proper personal protection, and properly functioning tools and equipment. Safety planning should include fall protection and confined space spans. Plans for exposure to toxic materials and for shielding against embankment collapse may be needed. Safety is practice that must be developed and reinforced on each job.

Agencies have comprehensive safety manuals. An example of the bridge inspection safety manual for New York State can be reviewed at https://www.dot.ny.gov/divisions/engineering/structures/repository/manuals/NYSDOT_Br_Insp_Safety_Manual.pdf. Daily safety meeting or pre-job safety meetings provide a reminder of the safety aspects of the job that may be encountered during the coming shift or job.

2.3.1.7 Work Procedures

The crew leader should visit the site and determine what work must be performed in order to develop the work plan. If a significant amount of time elapses between the work plan development and the work being performed, an additional visit to the bridge, closer to when the work is being performed, may be necessary to determine if changed conditions require a revision to the work plan. The magnitude of the work can change quickly. This can be especially true for bridge deck and joint work.

While at the site, the crew leader should determine the exact location and total units of work. Staging locations and storage of equipment and materials is also a consideration.

2.3.1.8 Job Assignments for Personnel

Performance standards aid in determining the required number and skills of the personnel that will be required for the task. If performance standards are not available, the required skills for each item of work in the outline of work previously prepared should be noted. The knowledge of the actual work that is to be done and the conditions at the work site may cause adjustments to the requirements. Variations may be required due to traffic considerations, unusual complexity of the job, material set or cure times and weather factors. The job needs should then be compared with the capabilities of the crew members and assignments made to appropriate individuals.

Individuals should be assigned specific tasks in accordance with their capabilities and the requirements of the job. Specific precautions or instructions should be given to the personnel at the time of the assignment. If required skills are not available among the crew, necessary personnel from other DOT units or contractors should be obtained.

2.3.1.9 Equipment Requirements

The performance standards aid in determining the type and amount of equipment required to properly perform the work. Modifications may be necessary due to unusual work requirements, personnel qualifications, or differences in the equipment available compared to equipment identified in the standards. If performance standards are not available, units of equipment required for items of work in the previously prepared outline should be noted. Back-up units may be necessary or alternative plans made so equipment failures will not delay completion, especially for critical tasks or when a reopening to traffic is mandatory.

Tools required for a task must be considered and compared with the equipment and tools available to the crews. If additional tools are required, these must be procured and brought to the site to avoid delays. Every crew should carry a set of standard tools and know the procedures to obtain back-ups in the cases for breakage or failure during the job.

2.3.1.10 Material Requirements

The amount of materials needed for the job can also be determined from the performance standards or estimated from past experience. Any materials requiring a special order should be obtained before the work begins. A reserve of the materials should be taken to the job site in case quantities were underestimated. Other materials that were not identified in the work order that might be needed, such as wood for forming, cribbing, or blocking, Steel plates and shims, concrete anchors, bolts, joint backing material, back filling material, concrete patching material, clean up items, etc. should also be included.

2.3.2 Scheduling

Once the job plan has been prepared, the work can be scheduled. Managers develop monthly work schedules and refine the schedule weekly. When scheduling work for the month, it is important that the maintenance activities be coordinated. Coordination includes performing similar work on multiple sites on the same day or in the same week to increase efficiency. Examples of good scheduling include repairing concrete on several bridges in the same area at the same time or cleaning and painting several adjacent bridges at the same time. Bridge maintenance should be coordinated with DOT units for traffic operations, public affairs, and with other construction and maintenance operations on the roadways.

At the end of each week, the schedule for the following week is developed. During this process the following steps should be taken:

- Check to see if any work scheduled for the present week will be carried over into the next week and possibly delay planned work.
- Review the work scheduling to see which new activities are to receive the highest priority.
- Review the monthly schedule to see what projects are scheduled and if adjustments are necessary.
- Determine the employee days, equipment, and material required for the week. If manpower is still available, additional fill-in projects should be identified.
- Complete the schedule by assigning crew members and equipment to the specific projects.

Inclement weather may disrupt the work schedule. It is important that other work is planned that can be performed in bad weather so that crew time will not be wasted. In many states, repairs are generally limited in the winter months. Since winter work performed is minimal, this period is ideal for the training of employees and the repair of equipment. Many states use bridge maintenance crew members to plow snow, fabricate precast concrete bridge elements, and perform other incidental jobs in the winter months.

2.3.2.1 Critical Path Scheduling Method

The Critical Path Method (CPM) is one method of scheduling sub-tasks of a project or maintenance procedure. CPM has many applications. CPM can be used for scheduling tasks within a work order or for the yearly activities of the entire maintenance unit.

In CPM**,** each activity is represented as a task on a network, and connecting lines are drawn to represent the time schedule to complete that activity. The following steps are typical for CPM:

1. Identify the activities
2. Determine the sequence of the activities
3. Connect activities in order of sequence
4. Enter the time required to complete each activity
5. Identify the critical path or the longest possible path to complete all activities
6. Update progress as tasks are completed

2.3.2.2 Identify Individual Activities or Tasks

A complete list of activities needed to complete the project must be made. This list can be prepared from the work outline or the work plan. Sequence and duration of activities are set in subsequent steps.

2.3.2.3 Determine the Sequence of the Activities

Determine the sequence of the activities in the project. The activities are sequenced according to their dependencies on one another. Activities must be analyzed and sequenced properly to achieve an accurate result. If linked incorrectly, an incorrect time frame or erroneous project completion date may result. If one crew is being used to perform similar activities, these activities must be sequenced.

2.3.2.4 Creating the Network

When all activities have been defined and sequenced, a network of activities can be created. The network is the ordinal coordination of activities.

2.3.2.5 Estimate Activity Duration

The time necessary to complete each activity is determined using workload standards or past experience.

2.3.2.6 Identify the Critical Path

The critical path is the longest-duration path through a series of tasks necessary to complete a project**.** Activities located on the critical path cannot be delayed without delaying the overall project. The critical path method of scheduling is often presented using a diagram that shows the specific tasks, their duration and sequence. This critical path diagram is often presented in a Gantt chart. CPM scheduling with automated Gantt charting is readily available in spreadsheet form or in project management software used by most transportation agencies. These software tools can help streamline the scheduling of projects that involve many tasks.

2.3.2.7 Updating the Gantt Chart

For longer duration activities, the critical path schedule must be updated based on actual activity accomplishments. A new path might be found and alternative schedules can be presented to accelerate the project. Sometimes it is necessary to incorporate extra work that was not part of the original critical path. Training in critical path method is commercially available and recommended for bridge maintenance employees responsible for planning work activities.

Critical Path Example – Perhaps the best way to understand the critical path method is by example. Consider a project to remove an old pourable joint seal and install a new one. The project has the following tasks:

1. Acquire the new pourable joint seal material
2. Acquire round foam backing for under the new joint
3. Remove the old pourable joint seal
4. Clean the inside concrete edges of the joint
5. Place the new foam backing into the joint

6. Extrude the new joint seal material into the joint

With the tasks identified, the sequence of activities is determined. In this case, the sequence is obvious, however there are still options. For example, a two-person crew could complete Task 4 in half the time compared to one worker.

The network of activities is developed next. The network requires two workers. A duration to each task is assigned (Table 2.10):

Table 2.10 Development of Network of Activities Table

Task	Time to Complete
1. Acquire the new pourable joint seal material	2 hours – Need to go to the store
2. Acquire foam backing material	10 minutes – Have material
3. Remove old joint material	20 minutes
4. Clean concrete surfaces	120 minutes
5. Place new foam backing material	10 minutes
6. Extrude new joint seal into prepared joint	20 minutes

The tasks, sequence, and time required for each task can be transformed into a Gantt Chart, as shown in Figure 2.5:

Task	Time Required and Sequence
Task 1 – Acquire seal material	120 min.
Task 2 – Acquire foam backing	10 min.
Task 3 – Remove old joint	20 min.
Task 4 – Clean The joint	60 min.
Task 5 – Place Foam backer	10 min.
Task 6 – Extrude new joint seal	20 min.
Total Project Time	3 hours and 50 minutes

Figure 2.5 Gantt Chart for Pourable Joint Seal Replacement

The gray entries are on the critical path. Task 2 is not in the critical path because while one person is going to the store for the pourable joint seal, the other person only needs 10 minutes to get the foam backer material (20 minutes are idle). Task 3 should not be started until all required materials are at the job site. Task 6 cannot begin until all previous tasks are completed. By having two people available, Tasks 1 and 2 are able to be completed at the same time. Additionally, 60 minutes are saved by having both crew members clean a portion of the whole joint (a 120 minute task). Although this is a very simplified example, it demonstrates the power of critical path scheduling.

2.3.3 Performing the Work

Performing the work is the process of actual completion of the work in the field. The work should be done in a manner that conforms to quality and performance standards.

The crew is responsible for reviewing the work plan with the crew and for assigning job tasks. The work crew leader should plan the work in detail. This usually involves determining the specific work methods (how to do the work), equipment requirements, materials needed, and staffing the actual performance of the work. The work crew leader may also make revisions or refinements to the work plan based on the input from the crew members who will actually be performing the work.

The crew supervisor reviews the safety plan for the job with the crew prior to the work. Safety aspects may include traffic control, personal protective equipment, heavy equipment usage, material safety, etc.

After the maintenance activity has been fully planned and scheduled, the focus of the crew shifts to executing the repair plan. The daily routine for any job consists of the following basic steps:

1. Maintenance yard housekeeping activities
2. Check of proper operation of equipment and vehicles at the yard
3. Preparation for the job at the yard and moving to the job site
4. Establishment of traffic control, if necessary
5. Performance of the work at the job site in accordance with the job plan
6. Cleanup after the job at the yard

The daily routine contributes to efficiency of performance of work. Each step has a number of subtasks that are identified below:

2.3.3.1 Housekeeping

The maintenance yard is the base of all operations. The yard must be maintained in good condition to facilitate field operations and ensure worker safety. Most states have a Safety Engineer or equivalent person that helps yard supervisors keep the yard safe in compliance with Occupational Safety and Health Administration (OSHA) requirements. Bridge maintenance supervisors should strive to develop a close working relationship with these support people, and work with them to develop a Standard Operating Procedure (SOP) for yard maintenance activities. Some items in the SOP include:

- Periodic update of material safety data sheets (MSDS)
- Periodic check of parked vehicles for fluid leaks
- Check of yard safety signs for compliance and legibility
- Check of stored materials to ensure they are safely stacked as appropriate
- Return of all flammable/combustible materials to the designated storage areas
- Periodic check of flammable/combustible material storage areas for compliance, and to ensure reactive materials are separated
- Proper storage of all compressed gas cylinders is in compliance with regulations
- Check and service of fire extinguishers as required
- Check and clean-up of all hazardous waste storage areas
- Disinfecting clean-up of all common areas (shower, toilet, shop floor, etc.) daily

Crew supervisors should maintain health and safety records for their crew members. The records should include dates of relevant training (respirator fit testing, fall protection, confined space, etc.) and medical testing (such as blood lead levels, etc.).

2.3.3.2 Maintain Equipment and Vehicles

Equipment and vehicles must be maintained in good working order. All equipment and vehicles should be checked with adequate lead time for repair and serviced prior to mobilization. Checks and services should be performed in accordance with the manufacturer's schedule and guidelines.

2.3.3.3 Yard Preparation

Prior to leaving for the job site, the crew is first assembled to determine if changes must be made in job assignments. The crew members should be informed of the tasks that each is to perform. This allows each crew member to know what the assignment is and what teams will work together. The crew then gathers the required equipment and material needed.

2.3.3.4 Site Activities

When the crew arrives at the work site, the crew leader should review the safety procedures to be followed on the job and should ensure that safety-related assignments are fully understood. Once proper traffic control has been established, the crew can proceed with the work. Traffic control cones, signs, and flags should be checked periodically and the site should be kept as clean and uncluttered as possible while the work is underway.

When the job is complete, the tools and excess material should be properly stowed prior to leaving the site. Once the site is clean and again suitable for traffic, the traffic control devices can be removed. To properly reopen the highway to traffic, signs and traffic control devices should start at the work site and proceed back from the work site in the opposite direction of traffic.

2.3.3.5 Yard Clean-up

There are tasks that must be performed after the crew returns to the yard. The tasks include:

- Storing the tools and materials in their proper locations
- Disposing of debris
- Preparing equipment for the next use
- Reporting the work accomplished

To save time the next work day, all equipment should be serviced, including adding gas and oil. Problems encountered with the equipment during the day should be reported. The final tasks for the crew lead is reporting the work accomplished during the day and ensuring that work for the following day is planned and resources for performing it are available.

2.3.3.6 Staffing

To ensure that the job can be performed properly, the crews should include personnel who have been trained to perform the tasks that are required. This includes such specialists as:

- Carpenters for form building and wood working
- Welders for steel work and certified welders for primary members
- Laborers for concrete and masonry work
- Operators for special equipment
- Paint crews

These specialists are able to perform a majority of the tasks. The remainder of the crew should be made up of general laborers who can assist the specialists and perform other required activities. In addition, the crew leader should have the necessary equipment and stockpiled material to ensure that the scheduled work can be performed.

2.3.3.7 Equipment

Standard equipment for each bridge maintenance crew should include:

- Fall protection
- Under bridge inspection vehicle for some bridges
- Flat-bed truck with winch and lifting equipment
- Pick-up trucks
- Pole trailer or unit for lengthy materials
- A variety of air-powered tools
- Air compressor
- Small concrete mixer or mortar mixer
- Oxygen and acetylene welding and cutting equipment
- Heavy duty jacks (20-ton to 50-ton hydraulic)
- Portable arc welder with electric service outlets
- Heavy-duty electric drill fitted with an electromagnet
- Small, portable high pressure water pump
- Sandblasting equipment
- Hand tools: steel, carpentry, concrete, and mechanical
- Staging (scaffolding)
- Painting and containment equipment
- Tow cable and chains
- Radio equipment
- Chain saw
- Heavy duty chain hoist
- Temporary bridge sections and parts (as needed)
- Bolt wrench appropriate for the method of high strength bolting used by the agency
- Pneumatic hammers
- Concrete Saws
- Digital camera to instantly record activities
- Miscellaneous survey equipment (tape, level-rod, etc.)

2.3.3.8 Materials

Each bridge crew should have a small supply of materials, especially for emergency repairs.

Materials can be ordered or accumulated from salvaged materials or taken from job site left overs:

- Supplies to maintain the type of expansion devices commonly used by the agency
- Timbers for blocking and cribbing
- Concrete repair products
- Bridge joint materials

- Assorted bridge planks
- Steel decking
- Assorted I-beams, angles, channels and plates
- Reinforcing steel
- Sheet piles
- Timber and steel piling
- Cement, mortar, mason sand, aggregates, stone fill
- Epoxy
- Painting and painting supplies
- Nails, spikes, bolts, nuts, washers, pins, lag screws

2.3.4 Reporting Bridge Maintenance Accomplishments

Once the bridge maintenance activity is complete, it is important to report the details of the repair operation. It is important to document the repair because future decisions are based on the information collected from each job. Information provided by workers allows managers to maintain:

- A historical record of maintenance and repair activities, quantities, and costs
- A record of regular periodic and special expenditures as a basis for developing future budgets
- A current record to establish cost/performance relationships
- A source of information used to identify trends, and the need for additional cost or work items
- A source of information for public relations, accomplishment reports, and defense of tort liability claims; and
- A record of costs versus budget

Reporting is the primary means of communication between maintenance and agency management. Work completions and the use of resources are reported as they occur. Work completions inform management that planned and scheduled maintenance goals have been met and provide data to account for funds.

Each agency has specific reporting requirements. The following is a brief description of the information requirements.

2.3.4.1 Who did the work

The crew and the individual in charge of the work should be specified. This allows the work to be charged to the proper department and allows future verifications and follow-up in case of discrepancies or claims.

2.3.4.2 Work accomplishment

Most MMSs have work order numbers associated with maintenance projects. This work order contains all the information regarding what work is to be done. The amount of work actually performed should be recorded. The performance standards name the basis for measurement. In addition, the bridge repaired should be reported by bridge identification number or by route and milepost, or both. This information makes the work part of the repair history of the bridge. This also provides a notification back to the inspector indicating the work has been completed.

2.3.4.3 When was the work done

Report the date(s) the work was performed. This information is helpful in determining when work should be scheduled in future years and is required for scheduling periodic maintenance, particularly preventive maintenance.

2.3.4.4 Where was the work done

The location of where the work was performed on the bridge should be included so that the site of the repair may be easily determined. Information such as span number, travel direction, lane number, beam number, substructure number, sign inventory number, etc. would be used to provide exact location.

2.3.4.5 What was the effort to accomplish the work

This reports the resources used and how the job was performed. The hours of labor, types of equipment, and types and amounts of materials used are included. This permits computing the cost of performing the work and provides utilization data. The information also permits the determination of monthly resource needs for use in future scheduling.

2.3.4.6 Reporting Procedures

The actual reporting of the work performed has many variations. Most states use maintenance management system software for reporting. Personnel in the field furnish most of the information for the MMS. The individual in charge of a crew has the best knowledge of what transpired. Good and accurate reporting is obtained when the crew leader performs the close out of a work activity immediately after the work is completed. Many agencies keep before and after digital photos to show the work that was done. Completed work also needs to be reported back to the agencies bridge management system.

2.3.4.7 Evaluating

Evaluating is the measure of quantity and quality of work. Provisions should be made so that those most involved with the actual work, the crew leaders for example, regularly receive information so they can assess their own performance. Evaluations are based on comparisons between like crews or personnel performing like tasks with due account taken for extenuating factors such as individual work site specifics. Comparisons are also made against standards, so the standards may be adjusted to make expectations reasonable and so that plans and budgets are more accurate. Evaluation is also the system element that serves to measure the effectiveness of all of the other elements and to provide the means by which not only bridge maintenance, but the personnel performing it, can be improved. A maintenance management system can supply the manager with the information to more effectively and efficiently accomplish their maintenance program. At the same time the system will increase the control of operations and provide credibility to the program since the manager will have information with which to respond to requests and justify budgets.

2.4 Bridge Maintenance Contracting

2.4.1 Introduction

Most agencies use contract maintenance for some portion of bridge maintenance work. Agencies contract for bridge maintenance work to meet peak workload or to get specialized equipment or skills. This section summarizes contracting approaches used for bridge maintenance.

2.4.2 Types of Maintenance Work Contracted

Almost any type of bridge maintenance work can be provided through contracts. Agencies may contract for specific activities such as bridge painting or deck sealing where the location of the work is very specifically defined. Alternatively, agencies may opt to contract for a broad range of maintenance activities in a defined geographic region. Agencies engage contractors that are available for “on call” emergency work on bridges. Many agencies balance the bridge maintenance workload between agency crews and contractors to make effective use of resources and to provide good service to the highway users.

2.4.3 Maintenance Contracting Approaches

There are two types of contracts that are frequently used for bridge maintenance work. In the most common types of contract, the agency defines how the work will be done. This contract is a method-based contract. In the other type of contract, the agency defines the expected outcomes of the work. This contract is a performance-based contract. The two types of contracts have different levels of contractor control over the work and associated risk for the completed work. Method-based contracting gives the agency more control over the work and more risk for the end product while performance-based contracting provides less control over how the work gets done, but comes with less risk to the agency for the end product.

Table 2.11 Contract Type Risk and Control Summary

Contract Type	Agency Control	Agency Risk Level	Contractor Control	Contractor Risk Level
Method-Based	High	High	Low	Low
Performance-Based	Low	Low	High	High

These two contract types have a number of variant forms that shift the degree of control and risk between the agency and contractor. There are maintenance needs that are more suited to one contracting method or the other. The variant forms of the two basic contracting types are summarized below.

2.4.4 Method Based Contracting Methods

Historically, agencies have used method-based contracts to control the work that is being performed. These contracts are either agency directed or specification based.

2.4.4.1 Directed Contracts

Contractors bid on directed contracts by submitting unit prices for an identified schedule of bid items. The items bid would be work that is likely to be necessary during the contract period, as well as a rough estimate of the work likely to be done. The individual bid items are summed up to determine the lowest bidder for the contract. Agencies may offer a directed contract for bid that covers a geographic region rather than specific bridges. Directed contracts typically pay the contractor by the amount of work they do.

In directed contracts, all of the risk for errors in quantity, plans, and site conditions falls on the agency, with minimal risk to the contractor. Directed contracts typically require significant agency resources to direct the contractor during their work.

Directed contracts minimize some of the financial risk to the agency because the agency has significant control over the work. In many directed contracts, the agency controls financial expenditure through the issuance of work orders for smaller portions of the total contract value. The issuance of work orders is a way to address fluctuating maintenance budgets.

2.4.4.2 Specification Based Contracts

In specification based contracts, the agency specifies how the work is to be performed. Key components of this type of contracting are plans and/or specifications that govern how the work is to be done by the contractor.

The agency risk associated with specification based contracts is high and the contractors risk level is slightly higher than in directed contracts. In specification based contracts, the contractor follows the agency defined specification; however, the means that they use to follow the specification is up to the contractor to determine.

Warranties have been used successfully on specification based contracts to ensure the desired project outcomes and length of service of the completed project. The warranties are backed by construction bonds issued to cover any necessary rework.

Specification based contracts are awarded to the lowest qualified bidder. If warranties are required by the agency, the costs of the bonds are included in the contractors bid.

The advantage of specification based contracts is that the agency retains control over the work through the specification. The control over the work comes with risk to the agency for any errors or omissions in the specification. Any changes to the specification after award can result in additional costs to the agency.

2.4.4.3 Job Order Contracting

Job order contracting is a variation of a specification based contract. A Job Order Contract (JOC) uses standard plan details for bridge maintenance and a universal specification for maintenance activities that are covered under the contract. The main characteristic of a JOC is that the quantity of work is indefinite. These contracts use a “price book” that has all the individual bridge maintenance bid items included. Unlike direct contracts, the price book has an extensive list of bid items covering virtually every maintenance task the agency performs. The price book also has no quantities estimated. The price book is the contractor’s bid price or mark-up from an indexed price for each maintenance item. The main difference between other specification based contracts is that the contractor does not know where or when the work will occur within a defined region. This contracting form allows the agency to issue work orders or “job orders” that specify specific locations where items in the price book are to be performed. The contractors have bid items for mobilization and traffic control in the JOC. This essentially allows the agency to enter into a contract without knowing the exact amount of any specific bridge maintenance item that will be needed. JOCs are known for minimization of claims that may otherwise arise from uncertain limits of work common with bridge maintenance.

2.4.4.4 Equipment Contracts

Contracting for specialized equipment not owned by the agency is a form of specification based contracting. An agency will enter into a contract for a variety of specialized equipment that is requested by task order and/or bid items. The contract has fixed “bid” prices for certain classes of equipment on an hourly, weekly, or monthly unit price basis. When the equipment is needed, the crew supervisor issues a task order for a duration of time. In some cases, the equipment may be offered with an operator as part of the contract unit price.

2.4.5 Performance-Based Contracting

Performance-based contracting relies on agency-developed performance specifications that defines the desired outcome of the work but not the methods or means used to achieve the outcome. Performance-based contracts are used to provide all aspects of maintenance on a single bridge or highway corridor known as total contract maintenance.

In performance-based contracts, the agency must define specific level of service requirements for each of the items or assets included in the contract. The success or failure of a performance-based contract depends on the terms defined in the contract document. The performance standard must be adequately defined to result in the desired outcome.

For performance-based contracts, the contractor is responsible for determining the effort associated with achieving the agency defined level of service. This contracting approach effectively shifts the risk of errors in the determination of quantities from the agency to the contractor.

2.4.6 Comparison of the Contracting Approaches

The following example demonstrates the difference between the contracting approaches.

In this simplified example, an agency wishes to contract for bridge deck spall repair work on multiple bridges in a region.

Under the directed contract, the agency solicits bids from multiple contractors. The agency verifies that the contractors are licensed and bonded. A contractor is selected based on the lowest unit cost. The agency then issues a work order describing the specific locations and quantity of spall repair to be performed. The agency verifies the work as it is completed and pays the contractor according to quantity of work completed.

Under a specification based contract, the qualified contractors are selected based on lowest bid cost. A work order is issued for specific locations and quantities to be repaired similar to the direct method. The contractor completes the work using methods that satisfy the agency specification. The agency verifies through field inspection that the work meets the specifications. The contractor is paid based on the unit quantity of work completed according to the specifications.

For the first two methods, the agency performs its own quality assurance program to ensure compliance on the part of the contractor.

To use a performance-based contracting method, the agency must first develop a performance specification that completely defines the level of condition expected for bridges in the region and the level of deviation from this expectation that will be tolerated before a finding of non-compliance. The agency solicits bids from qualified contractors based on the performance specification. The contractors submit fixed price cost estimates to complete any spall repair work necessary to meet the performance specification over a defined period of time. With this approach, the contractors bid is based on their estimate of the current and future spall repair needs for the defined performance over the duration of the contract. The agency then monitors the performance of the contractor in keeping bridge deck spalling within the performance requirement. Payments are made to the contractor on a regular basis when the performance meets the defined level of service.

2.4.7 Common Methods of Payment

The agency has several options for how the payment to the contractor will be structured for maintenance contracts.

A common payment approach used for method-based contracting is unit payment. This payment approach can be used for directed or specification based contracts. Using this payment approach, the agency pays the contractor for the amount of work completed in accordance with bid unit prices.

If the work can be defined with a high degree of certainty, the agency may opt for a lump sum payment. Using the lump sum payment, the agency pays the contractor a single price to complete the work. The lump sum approach can be used with specification based contracts, but is not well suited for directed contracts because the quantity of work is not always defined at the time the contract is bid. Performance-based contracts are typically bid as lumps sum and paid in installments according to the contract payment schedule if performance is adequate.

If it is too difficult to define the amount and scope of work, it may be necessary to resort to a cost reimbursement contract, or force account contract. In contracts of this type, the contractor is reimbursed for their labor, equipment, and material costs at predetermined rates. Cost reimbursement contracts require a great deal of inspection and record keeping on the part of the agency to verify the contractor's charges. Another problem with cost reimbursement contracts is that there may be a perceived, if not actual, loss of competition. The contractor may be perceived to be working at a slower rate to increase labor costs, or using newly purchased material to increase their mark up on materials. These steps by contractors to make more money in a cost reimbursed contract means that the agency representatives is not only there to monitor quality in accordance with agency standards (specifications), but also to monitor productivity and measure quantities. Even if the inspector is not satisfied, it is difficult to document poor performance unless it is well below standard. The following table summarizes the payment options for common situations encountered in bridge maintenance contracting:

Table 2.12 Maintenance Contract Payment Methods

Payment Type	Directed	Specification Based	Performance-Based
Unit Price	Yes	Yes	No
Lump Sum	No	If scope is well defined	Yes
Cost Reimbursed	Yes	Yes	No

2.4.8 Methods of Contractor Selection

For all types of contract, the method used to select the contractor must also be determined. Options for contractor selection are presented in the following sections.

2.4.8.1 Lowest Responsible Bidder

A common contractor selection method is to select based on lowest responsible cost. Under this approach contractors respond to a request for bid by submitting a detailed cost estimate along with other required documents. The bid with the lowest "responsible" cost estimate is awarded the contract. A responsible bid may be evaluated using a number of methods, but often involves some analysis of cost deviations among the bidders.

2.4.8.2 Qualification and Negotiation

The qualification and negotiation approach begins by the agency reviewing the qualifications of the contractor. Those contractors that are deemed qualified then enter into negotiations with agency to determine the price for the work to be performed. This approach is common for engineering and design services. Under this selection method, the contractor is selected based on qualifications and not solely on cost.

2.4.8.3 Best Value

The best value selection approach is a hybrid of the two previous methods. Using the best value approach, technical qualifications are used to develop a short list of contractors. The short listed contractors are asked to submit a technical proposal and cost proposal in two separate packages. The review panel evaluates the technical proposals without opening any of the cost proposals. Once the technical proposals have been assigned a score based on an agency defined evaluation criteria, the cost proposals are opened and ranked independent of the technical proposal scores. The two component scores are combined into a total proposal score. The contractor with the maximum combined score is selected.

2.4.8.4 Summary

Contracting for bridge maintenance can be useful. Contracts can be directed or performance-based. Within these general categories there are a number of variations of how the costs are determined and how much flexibility the contractor has to determine how the work is performed. Likewise the various contracting options provide varying levels of control over the work and costs for the agency.

2.4.9 Comparing the Cost of In-House Crews Versus Contracting

When determining whether or not to contract, or when estimating the total cost of a project to be done by contract, the incidental costs of contracting should not be neglected when developing estimates. Incidental costs can be appreciable, and they can vary with the type of contract. Costs incidental to contracting include:

- Administrative costs of preparing requests for proposal or bid documents
- Costs of selecting the contractor or vendor *(*particularly for negotiated contracts)
- Administering the contract while the work is being done
- Inspecting the work
- Field record keeping
- Consultations with the contractor
- Verifying charges, approving final results, and approving invoices for payment

There is a tendency when comparing contract to in-house cost to compare the salaries of the agency employees with those of contractors and ignoring the hidden cost to the agency. Other costs of performing work in-house that should be considered include:

- Overhead costs such as employee benefits, work space and administrative support
- Cost of keeping employees on the payroll during bad weather, during winter months, or when the workload is light
- Cost of purchasing equipment and keeping it operational
- Liability costs associated with the maintenance operation such as injury to employees or the traveling public

2.5 Quality Control and Quality Assurance

2.5.1 Introduction

Quality control and quality assurance programs are important parts of an agency's overall bridge maintenance program. Quality assurance establishes process and procedures that will lead to high quality maintenance. Quality control programs verify that the quality standards established are being met.

2.5.2 Quality Control / Quality Assurance Definitions

The terms quality control and quality assurance are often incorrectly used interchangeably. One basic distinction between the two is in the timing of when the quality is influenced. To properly apply these concepts we need to first understand the difference between them as they apply to bridge maintenance.

2.5.2.1 Quality Assurance (QA)

Quality Assurance (QA) refers to the processes or procedures used to perform bridge maintenance. Quality assurance makes sure you are doing the right things and in the right way. Examples of quality assurance include process checklists, repair procedures and standards development.

Quality assurance activities are determined before production work begins. Quality assurance is also the compliance with those checklists, procedures, and standards as activities are performed while the repair is underway. QA aims to prevent inferior work with a focus on the process used to perform the repair. QA is a proactive quality process.

2.5.2.2 Quality Control (QC)

Quality Control (QC) refers to activities associated with the creation of project deliverables. Quality control is used to verify that deliverables are of acceptable quality and that they are complete and correct. In other words, quality control makes sure the results of what you've done are what you expected. Examples of quality control activities include inspection and testing process.

Quality control activities are performed after the work is complete. QC aims to identify and correct defects observed or measured in the finished product. Quality control is a reactive process.

2.5.3 Quality Management Plans

A Quality Management Plan (QMP) combines the objectives, standards, activities, and measures of the quality assurance and quality control program into a single plan to address the overall quality of bridge maintenance. The QMP defines the acceptable level of quality and describes how the maintenance crews will ensure this level of quality in their deliverables and work processes. The QMP describes the following quality management components:

- Quality objectives
- Project deliverables and processes to be reviewed for satisfactory quality level
- Quality standards
- Quality control and assurance activities
- Quality roles and responsibilities
- Plan for reporting quality control and assurance problems

2.5.4 Quality Assurance in Bridge Maintenance

A good bridge maintenance program requires that the agency ensure bridge maintenance activities are being done in the proper way. Agencies that employ quality assurance typically focus their quality assurance efforts in the following areas:

- Standards development
- Work Procedures
- Employee Training

2.5.4.1 Quality Assurance Standards

The quality assurance standards are a set of desired outcomes. These standards define quality bridge maintenance repair. For example, consider the desired quality standards for a concrete deck repair activity. A quality assurance standard for this type of repair might include the following quality standards:

- The newly placed concrete shall be solid and crack free
- The spall repaired area shall be at the same finished grade as the surrounding deck
- Acute angles shall not be permitted in a spall repair
- The defined surface friction shall be present in the repaired area

The criteria presented above establishes the expected quality outcome for a concrete bridge deck spall repair activity. The crew uses defined work procedures to achieve the desired quality in the finished repair.

2.5.4.2 Work Procedures

Work procedures outline the steps necessary for the proper completion of a bridge maintenance repair. As an example, consider the repair of a concrete bridge deck spall. A work procedure for this activity might look like this:

Suggested Procedure

Concrete Deck Repairs

1. Identify the deck location to be repaired
2. Control traffic in accordance with traffic management plan
3. Hammer sound or chain area around the spall to identify and mark adjacent unsound concrete.
4. Sawcut to a depth of at least ¾ inch in a geometric pattern 1 inch outside the lines marked in the previous step.
5. Use a lightweight chipping gun to chip the concrete out between the edge of the spall and the sawcut lines. Remove the concrete to at least 1 inch below the top mat of reinforcing steel.
6. Use sand blasting equipment to remove any rust from exposed reinforcing steel.
7. Replace any missing steel with proper overlap lengths. Consult an engineer as necessary.
8. Remove any loose concrete material or other debris from inside the spalled area.
9. Wet the concrete in the spalled area and surrounding but do not allow standing water.
10. Mix rapid setting concrete and place concrete in the spalled area up to the surface of the surrounding deck.
11. Use a 2 by 4 or similar lumber to screed the newly placed concrete to the level of the surrounding deck.
12. Use a wet broom to provide a roughened surface in a transverse direction to traffic.
13. Use water and broom to clean the areas around the newly placed concrete.
14. Remove all materials and tools from the work site while the concrete is setting.
15. Allow the concrete cure to achieve adequate strength before restoring service to traffic.
16. Remove the traffic control and restore service after the concrete has set.

With a procedure similar to the example shown above, it is clear what steps are needed to end up with a good quality spall repair. Work procedures similar to this example can be created for all bridge maintenance activities. The establishment of defined work procedures is an essential tool to ensure that bridge maintenance activities are done consistently from job to job and from crew to crew. Adherence to the defined work procedures will help ensure that good quality is achieved.

Note that throughout this manual, suggested procedures will be flagged in call out boxes such as the one shown above. These procedures are only suggestions and should be confirmed by management.

2.5.4.3 Employee Training

Proper training is an important component of quality assurance for bridge maintenance activities. For example, it isn't reasonable to expect that a bridge crew member could meet the required quality standards for welding without appropriate training. Likewise, the resulting quality of a bridge painting project is likely to be below quality standards if the painters are untrained.

To help ensure that employees are able to meet the quality requirements, training standards for crew roles should be developed. The training standards should define a set of training that is required and desirable for various crew member functions. These training standards need to consider the type of work the crews will be performing and the need for specialized skills for crew members.

For example, a bridge painting crew is considered. Every employee working on the crew will require a suite of common health and safety training such as fall protection, confined spaces training and lead health and safety training. These training courses ensure that the employees are working safely but do not address the quality of the work being performed. Training courses related to the proper preparation of steel surfaces for painting, how to monitor weather during painting, and application techniques for paint ensure that the painting will meet the quality standards.

An agency with training standards defined for each role on their crew can compare the current staff training histories against the standards to identify training needs and to assign tasks in a project work plan.

2.5.5 Quality Control in Finished Products

Quality control processes are used to check or test completed work by identifying any defects observed or measured in the finished product. Quality control is a reactive process of sampling and testing to ensure conformance with established quality standards. Quality control is reactive in nature, but can be employed at the completion of intermediate phases of a larger project. For example, the QC activities associated with the placement of new paint on a bridge would certainly include some form of QC of the condition of the metal and quality of the surface preparation before the paint was applied.

It may be necessary to adjust the frequency of verification testing in accordance with the estimated number of QC tests to be performed to space out the testing dates. The rate of verification testing may also vary based on the risks involved. For example, testing structural concrete may be more frequent than testing embankment materials. QC testing may include visual inspection for workmanship and quality of the finished product, and material testing for adherence to established material specifications.

Quality control efforts require documentation of the results of the inspection, sampling or testing that is done. The agency should specify the minimum level of QC documentation that must be provided in the QMP. Materials or workmanship that do not meet the specified level of quality should be properly documented, including the nature of the non-conformance, location, extent, and disposition (e.g., removed and replaced, reworked, accepted based on engineering judgment, etc.). The documentation is also used to provide feedback for improvement of the quality assurance procedures.

2.6 Chapter 2 Reference List

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