Forest Products Laboratory

General Technical Report FPL–GTR–223

In cooperation with the

United States Department of Transportation

Federal Highway Administration

United States Department of Agriculture
Forest Service

Covered Bridge Security Manual

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Abstract

The design, construction, and use of covered timber bridges is all but a lost art in these days of pre-stressed concrete, high-performance steel, and the significant growth both in the volume and size of vehicles. Furthermore, many of the existing covered timber bridges are preserved only because of their status on the National Registry of Historic Places or the diligent maintenance and care of the owners of these structures, or both. Of the covered timber bridges that remain in the United States, only a small percentage still stand today because of arson, vandalism, neglect, natural disasters, and other factors. The objective of this work is to provide covered timber bridge owners with the tools to quickly and efficiently design and implement a security system to protect these important historical landmarks. This goal was obtained with an in-depth analysis of equipment based on the practicality in a covered bridge application. Other major considerations required for all equipment to work efficiently within a security system are also fully discussed, including, but not limited to, maintenance, power requirements, and general set-up of an integrated security system. A comprehensive case study is presented involving monitoring systems placed on five of the six covered bridges in Madison County, Iowa, at the end of this report to showcase the abilities of an integrated system and all the decisions that must be made throughout the process for the entire system to work as intended.

Keywords: Covered bridges, wood bridges, security

May 2013

Phares, Brent; Wipf, Terry; Sievers, Ryan; Hosteng, Travis. 2013. Covered bridge security manual. General Technical Report FPL-GTR-223. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 34 p.

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The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

Contents

This study is part of the Research, Technology and Education portion of the **National Historic Covered Bridge Preservation** (NHCBP) Program administered by the Federal Highway Administration. The NHCBP program includes preservation, rehabilitation and restoration of covered bridges that are listed or are eligible for listing on the National Register of Historic Places; research for better means of restoring, and protecting these bridges; development of educational aids; and technology transfer to disseminate information on covered bridges in order to preserve the Nation's cultural heritage.

This study is conducted under a joint agreement between the Federal Highway Administration–Turner Fairbank Highway Research Center, and the Forest Service – Forest Products Laboratory.

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Covered Bridge Security Manual

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Introduction

Covered bridges used to cover the American landscape from coast to coast. However, because of various factors including neglect, arson, vandalism, and natural disasters, currently less than 700 to 900 bridges are still in existence today. Covered bridges tend to be in isolated areas, and they are constructed with a flammable material, which makes them highly susceptible to arson and vandalism. Because they are usually far from populated areas, it is difficult for firefighters to arrive at the bridges in a timely manner once a fire has been set. This makes it likely that any fire may cause critical damage or may completely destroy a bridge. Most of these covered bridges are covered by volunteer fire departments, which only adds another level of complexity to the situation. It is essential that we protect and preserve these standing landmarks throughout our country for future generations. One way to provide the necessary security is to use remote monitoring and other security systems to protect them from trespassers.

Multiple bridge owners throughout the United States have taken measures to ensure the safety and integrity of their covered bridges by implementing structural strengthening, fireproofing, and monitoring systems. Common protective methods entail illuminating the bridge site and using fire-retardant material around important structural members. These methods are typically used because they are usually very cost effective. Unfortunately, these systems are passive approaches and provide no mechanisms to alert the proper authorities and increase the chances of survival for the bridges.

This report is intended to assist covered bridge owners in selecting systems that will protect covered bridges with the option of adding active alerts to proper authorities for the purpose of heightening security. Because very little technical literature exists dealing exclusively with the subject of security and monitoring systems for covered bridges, we contacted multiple Departments of Transportation (DOTs) with a high concentration of covered bridges as well as multiple bridge owners to assess the state of covered bridge security in the United States. This insight from bridge owners coupled with technical literature about physical security of other assets is the basis of this report.

Overview—Covered Bridge Surveillance Project, Iowa State University

In 2005, the Bridge Engineering Center (BEC) at Iowa State University (ISU) completed a case study on remote security of historic covered bridges by designing and implementing an active monitoring system on the Cedar Covered Bridge in Madison County, Iowa (Phares 2006). The security system installed on the Cedar Bridge is discussed further in the case studies portion of this report. The work completed and the system developed for the Cedar Bridge resulted in the BEC receiving a grant from the Federal Highway Administration (FHWA), through the National Historic Covered Bridge Preservation Program (Matias 2011), to install remotely monitored security systems on the other five covered bridges in Madison County. The five bridges included in the security monitoring grant, the Cutler–Donahoe, Holliwell, Hogback, Imes, and Roseman covered bridges, are five of the six landmark bridges that remain in Madison County and the only bridges that have not been completely rebuilt. The Hogback Bridge was partially damaged by arson but managed to survive and was restored to its original condition one year after the incident. The Cedar Bridge, made famous by the book, *The Bridges of Madison County* by Robert James Waller, was completely destroyed by arson in 2002 but rebuilt to original specification in 2003–2004 (Overington 2003).

For the Cutler–Donahoe, Holliwell, Hogback, Imes, and Roseman bridges, we decided to design a basic system with a high degree of functionality that could be tailored to fit the majority of covered bridge sites encountered rather than to design a security system to be specific to a given bridge site. The developed security system includes two flame detectors, an infrared camera, an optical camera, and multiple pieces of communication equipment necessary to relay all the information back to the design team as well as to officials in Madison County. We were required to install an alternative energy system at the Hogback Bridge site because it is so distant from local grid power. An in-depth analysis of the security system for these five bridges and problems encountered can be seen later in this report.

The implementations in Madison County were not completed to show what every covered bridge monitoring system should entail. Rather, they provided a mechanism to showcase different ideas, constraints, and limitations for designing a surveillance system for other bridges. This manual is intended to showcase the most predominant and functional technology in the area of surveillance and monitoring at the time of its preparation.

Scope of Work

This manual is intended to provide covered bridge owners with a tool to aid in the development and deployment of security strategies. The research team has completed an extensive government literature review at the local, state, and Federal levels, which included contacting several DOTs and local governments with a high concentration of historic covered bridges that have installed, or are planning to install, security systems or other preventative measures on their bridges. Multiple companies that specialized in outdoor security systems were contacted to define cutting-edge technologies in the security industry at the time this report was written. Note that this manual is not intended to be an all-inclusive list of possible security system equipment and tactics, but a guide to best practices, techniques, and equipment.

Literature Review

Pertinent Covered Bridge Literature

Very little information related to the security of covered bridges has been published. As a result, the majority of the information summarized here deals with general security of bridges or general asset security.

Although there is a lack of published literature dealing exclusively with covered bridges, numerous professionals throughout the country have substantial knowledge related to covered bridges. When possible, these professionals were contacted to provide additional information.

The Beginning of Covered Bridges in the United States

The first covered bridges in the United States appeared in the Eastern states in the early 1800s and thereafter were constructed across the country until the early 1900s when steel bridges became a more economical choice for bridge construction. Covered bridges built during this period were built to reflect the architectural style of a specific time and place while still being a functional and vital passageway for the community. Numerous builders and architectural styles created unique structures that personified communities around the country.

As years passed, the covered bridge became a romanticized icon of the United States of the 1800s. As bridge and road design became routine and repetitive, the distinctive architecture of the past started to stand out more and more when compared with its modern counterpart. Although new construction of covered bridges ceased around the turn of the 20th century, they were still used well into the new century and many continue to be renovated and repaired for use today and well into the future. Despite the best efforts to preserve the bridges at the turn of the 20th century, many covered bridges were lost to neglect, fire, flooding, and other disasters both natural and manmade (Becker 2011).

Different statistics vary about how many covered bridges were constructed and how many still stand today. However, it is clear that a relatively small percentage still stand today when compared with the turn of the 20th century. Recently, the Federal government as well as multiple state and local governments have placed significant emphasis upon preserving our covered bridges. This is evident by the allocations in governmental budgets for spending on covered bridge preservation. Many bridge owners are currently installing security systems to provide protection against arson and vandalism or plan to do so.

Structural Integrity

The bridges were covered for several different reasons. Many historians believe it was to give the appearance that the bridge was a barn and this would have a calming effect on farm animals as they crossed waterways that would otherwise startle them. People also believe that that the bridges were covered to protect travelers who were caught in inclement weather or to hide people on romantic strolls. These ideas may have been considered by the builders when putting coverings on their bridges; however, the main reason that bridges were covered was for a more practical and functional reason. Designers felt that by covering the heavy and expensive trusses from direct rainfall and sunlight, the life expectancy of the bridge could be extended. The designers were correct; history has proven that a covered bridge will last up to three times longer than a similar non-covered bridge. Although the sacrificial wall and roof cover-

Table 1. Bridge fires (1992–2002)

Year	Bridge name	Comments
1992	Loy's Station	
1992	Parker	Survived
1993	Slate Bridge	
1993	Jordan	
1993	Corbin	
1993	Smith	
1993	LeMay Ferry	
1993	Nectar C.B.	
1993	Sells	
1993	Kilgore Mill	
1994	Wolf Bridge	
1994	Grimes	
1994	Guilford	
1994	Kaufman's Distillery	
1994	Upper Sheffield	
1995	Miller Road	Survived
1996	Wimer	Survived
1996	Carman	
1997	Offult Ford	
1997	Lower	
1997	Wilkinson	
2000	Henniger Farm	Survived
2001	Pine Grove	Survived
2002	Ryot Bridge	
2002	Orne Bridge	
2002	River Road	
2002	Cedar Bridge	
2002	Henderson	Survived
2002	Risser's Mill	
2002	Jackson	Survived
2002	Jeffries Ford	
2002	Woodsville	Survived
2002	Newfield	Survived
2002	Wilson's Mill[a]	Survived

[a]Wilson's Mill Covered Bridge (Avella, Pennsylvania) is thought to have survived because of a metal deck.

ings would have to be replaced every couple of decades, it was still a more economical choice than completely replacing the bridge or structural trusses in the same time frame. The ability to extend the life of timber truss bridges by using sacrificial wall and roof coverings was discovered early in the age of bridge design in Europe and other parts of the world and was an integral part of timber bridge concepts when it arrived in North America (Becker 2011).

Targeting Covered Bridges: Arson and Vandalism

Experts estimate that over 176,000 intentional outdoor fires are set by arsonists every year. These fires result in approximately 20 deaths, 250 injuries, and $23 million in losses annually according to Volume 9, Issue 6 of the Topical Fire Report Series (National Fire Data Center 2009). Out of all the outdoor fires that occur every year in the United States, 27% are intentionally set by arsonists (National Fire Data Center 2009). Arson is a prevalent problem in the United States that destroys property and life and must be addressed in a serious manner. Intentionally set outdoor fires tend to be more common in the spring from March and April and once again in mid-summer, especially July 3–5, according to the National Fire Incident Reporting System (NFIRS). Because these are the times when arson is most likely to occur, it is recommended that, at a minimum, the highest level of security be active during these time periods.

The devastating effects of arson are evident when committed on covered bridges in small towns all over the country. Unfortunately, this kind of damage is prevalent throughout recent history as seen in Indiana (Rinehart 2005), Iowa (Overington 2003), and Pennsylvania (Murphy 2008). The number of covered bridges throughout the United States is quickly dwindling because of arson as well as neglect. On average, over the last 20 to 30 years, two to three bridges apparently have been set on fire with one or two of these bridges being completely destroyed, as shown in Table 1. It is essential that cities and states that own and maintain covered bridges take the proper measures to ensure that these bridges will survive for future generations to enjoy.

Indiana

In 2005, a fire destroyed one of the 31 covered bridges remaining in Park County, Indiana. The Bridgeton Bridge was beloved by all in the area and was known as the most photographed bridge in the county before the fire. A 35-year-old male, who was a person of interest in an arson case with another covered bridge in the area, seemingly poured an accelerant across the length of the bridge and ignited it sometime around midnight. Both of the bridges were completely destroyed and collapsed. A few months prior to these arson cases, firefighters were able to save another bridge, which also appeared to be intentionally set on fire (Rinehart 2005).

Iowa

Madison County, Iowa, is well known for its covered bridges because of the popularity of the 1992 book, *The Bridges of Madison County,* and the 1995 movie adaption with leading actors Clint Eastwood, Meryl Streep, and Annie Corley. None of the six remaining covered bridges in the county were made as popular by the book as the Cedar Bridge, which is on the cover of the book and is a central bridge throughout the entire story. On September 3, 2002, the Cedar Bridge was completely destroyed by arson, only 4 years after over $128,000 was invested in restoration. The town was extremely distraught over the loss of the bridge, given the large amount of tourism it brought to the community and the manner in which it was destroyed. This prompted the city to replace the structure with an exact replica with as similar of construction techniques as possible the next year (Overington 2003).

Pennsylvania

One of the three remaining bridges in Erie County, Pennsylvania, was set ablaze in December 2008 by two local men. The destruction of this particular bridge was damaging to the city for two separate reasons. The historic Gudgeonville Covered Bride in Girard Township was valued at over $1 million and was of great importance to local tourism and also a vital part of the roadway system that still carried traffic over the Elk Creek. Both of the men responsible for these crimes were suspects in other crimes throughout the area including burglary, criminal trespass, and theft that are all unrelated to the bridge incident (Murphy 2008).

Although arson is a major problem throughout the United States, especially when it pertains to covered bridges, several steps can be taken to reduce the chances of trespassers committing destructive acts toward the covered bridge. In this report, we discuss several successfully implemented recommended procedures for covered bridge security around the United States. With care and diligence, the probability that arson and vandalism will occur on a particular bridge can decrease significantly.

Importance of Historical Integrity

It cannot be stressed enough that any modifications completed on covered bridges including security systems or any other type of rehabilitation must be completed with the greatest of care to ensure that the historical significance of the covered bridge is preserved. The National Register of Historic Places has strict guidelines as to what will and will not be accepted as a historical place. To be eligible for some funds from government agencies to preserve a covered bridge, it is important that a covered bridge is on the register of historic places before and after any modifications. The National Register of Historic Places has strict criteria that must be met for all historic places. It is important that all bridge owners be aware of these criteria before embarking on any project in, on, or around a covered bridge.

Listing in the National Register of Historic Places provides formal recognition of a property's historical, architectural, or archeological significance based on national standards used by every state. Benefits include the following:

- Becoming part of the National Register Archives, a public, searchable database that provides a wealth of research information.
- Encouraging preservation of historic resources by documenting a property's historic significance.
- Providing opportunities for specific preservation incentives, such as
    - Federal preservation grants for planning and rehabilitation
    - Federal investment tax credits
    - Preservation easements to nonprofit organizations
    - International Building Code fire and life safety code alternatives
- Possible state tax benefit and grant opportunities.
- Involvement from the Advisory Council on Historic Preservation when a Federal agency project may affect historic property.

Physical Security of Structures

Physical security is a basic principle necessary for the survival of any person, place, or object. Throughout history, people have used security to protect their privacy, property, and lives whether it be with a weapon, by constructing large impenetrable walls, or more recently by using cameras or other monitoring devices to detect and apprehend ill-willed individuals. By definition, security means the freedom from danger, fear, or anxiety (Merriam Webster Dictionary). By this definition alone, security covers a wide array of areas including information, physical, political, and monetary, as well anything that requires protection from danger. To some degree, there is a concept of security dealing with almost all areas of life, which makes it difficult to cover security in depth at all levels.

Structures can come under attack from terrorism, sabotage, natural disasters, and other threats that may be unique to a particular area. It is essential when designing a security system for a certain structure that a full analysis is done to ensure that the level of security required is obtained. Designing a security system for any structure is always a case of planning for unknown dangers in type and magnitude, with the understanding that not all security risks and dangers can be prevented, deterred, or even detected.

Numerous security measures can be taken for all types of structures whether it be a bridge, building, or any other type of asset. Many of these types of security will not transfer from one type of structure to another. A building, for example, may be under a high level of security by only allowing traffic through approved entrances and restricting all unwanted entry through physical barriers or alarm systems or both. Although the ability to completely monitor all traffic going through and around the structure is ideal for almost all applications, it is not necessarily the most feasible. This is especially true for bridges, which are designed to allow traffic to flow easily. Security measures that require stopping and checking all modes of transportation using the bridge would prove to be uneconomical and unreasonable. However, many precautions and security measures may be implemented to greatly increase the security of the structure and decrease the probability of dangerous behavior occurring.

Blue Ribbon Panel Workshop on Bridge and Tunnel Security

In 2003, the FHWA organized a Blue Ribbon Panel (BRP) Workshop on Bridge Security Assessments following the terrorist attacks of September 11, 2001, to analyze the safety of the transportation infrastructure (DOT 2003). The BRP was given the objective to "Develop short- and long-term strategies for improving the safety and security of the nations' bridges and tunnels, and provide guidance to highway infrastructure owners/operators." The BRP decided upon five major levels of security to construct an effective defense against unwanted activities on or toward bridges. These levels include 1) deter, 2) deny access, 3) detect presence, 4) defend the facility, or 5) design structural hardening to minimize consequences to an accepted level. The BRP report goes into detail about designing structural hardening but does not go into much detail about the other four areas.

Although all levels of security are not equally discussed in full detail within the BRP report, the research team felt it was prudent to investigate and discuss all five levels of security in greater detail. By considering all five levels of security when developing a security system for a bridge or any other structure, the owner is able to assemble a system that is not only effective, but redundant, and that provides the greatest level of security possible for the given budget. Within this report, the concept of structural hardening is covered only briefly as several different publications look at structural hardening of bridges and covered bridges in particular. This report's main goal is to complement these publications with the other four main portions of security discussed within the BRP's assessment. Below, these four levels are briefly discussed; furthermore, multiple examples of each of the areas are discussed within the equipment options portion of this report.

Deter

Deterrence is prevention or discouragement of a detrimental action by means of fear or doubt. For the case of bridge security, the fear created would be that anyone who would commit detrimental actions to the bridge would be caught and prosecuted. One of the more inexpensive options for deterrence would be to place signs around the bridge, alerting all visitors that surveillance equipment and alarms are implemented on site, and local authorities will be alerted of any trespassers after hours. Quite simply, the presence of this type of sign creates fear or doubt (whether or not the surveillance equipment actually exists or not).

Greater levels of deterrence can be implemented if the designer of the security system believes that the bridge is more susceptible to arson or vandalism. For example, in extreme situations, deterrence by means of onsite security personnel may be warranted. Additional levels of increased security may include lighting, barricades, or alarm systems placed such as to frighten any trespassers off the premises. In some cases, the goal of these measures is, quite simply, to create a sense of uncertainty and fear about a particular site.

Deny

Denying trespassers access to the bridge site is one of the more difficult portions of the security program laid out by the BRP. Because most covered bridges are in secluded areas, trespassers may enter the site several different ways. Many of the methods used for deterrence can also be able to deny trespassers to a limited degree. The use of fences and barricades around the bridge area could deny, or at least slow down, potential threats to the bridge.

Detect

In the case of arson and vandalism, surveillance of the bridges is a great first step in the detection. An added benefit is that, once detected, other steps can be taken to lessen the probability of total destruction of the bridge, as will be discussed further. Much of the equipment discussed in this report pertains to the detection of threats. The detection of threats can be an invaluable portion of many security systems. This detection of threats is important because it facilitates alerting local authorities if there is anything going on at the bridge site.

Defend

The ability for the covered bridge to defend itself once a fire has been started can be essential for the survival of the bridge. There are multiple ways to defend a bridge such as sprinkler systems or the application of fire-retardant paint or wood during construction or renovation. Defense is fundamentally different from structural strengthening, as the addition of defensive measures does not change the bridge in a structural sense but only protects the existing structure from fire.

Education

Although all of these physical security measures are important to ensure the highest level of security at a covered bridge, the importance of education should never be overlooked when discussing preventative measures against arson and vandalism. By educating the public in areas surrounding a covered bridge about its historical significance and the importance of preserving the structure, awareness of the bridge is increased and those who take interest in a sense become added security to the bridge. This can easily be done by placing articles in local newspapers, going to local middle and high schools to discuss the history of covered bridges, posting signs, and many other options.

Covered Bridge Monitoring System: Design

Preliminary Decisions

Multiple decisions must be made to deploy an effective security system that can fulfill the needs and desires of each bridge owner. Some of these main decisions are discussed in detail within this section; however, these decisions and discussions may not be all inclusive, and proper discretion should be used when implementing a covered bridge security system. Illustrated in Figure 1 are some of the more major decisions that go into designing a security system.

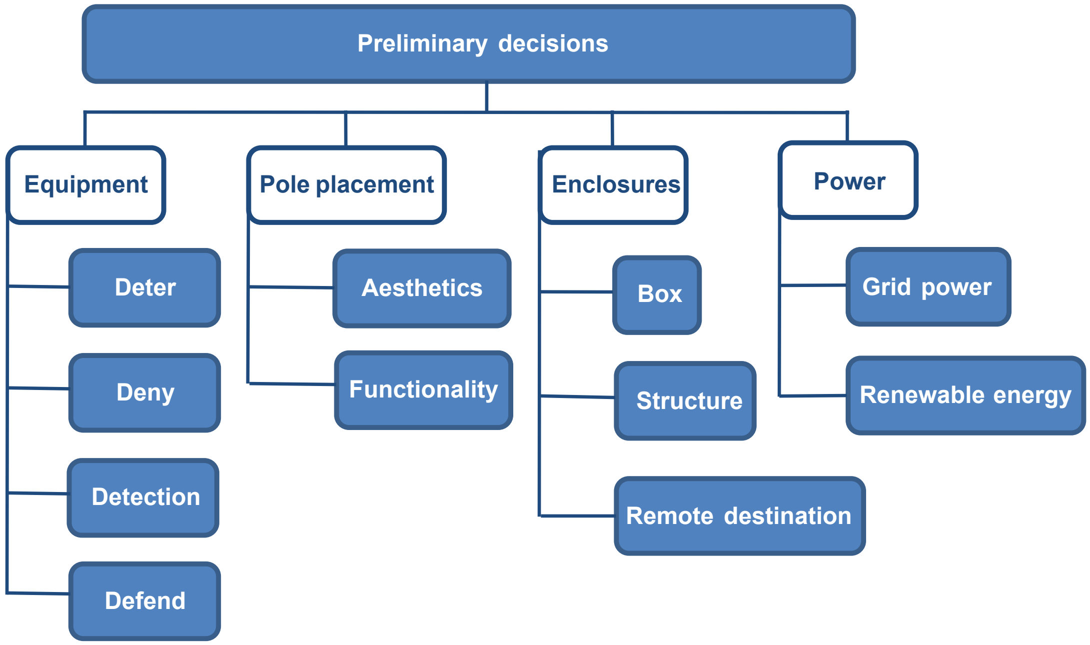

Figure 1. Equipment options.

Subsequent sections provide more detail regarding the information and terms presented in Figure 1 to give the designer a more detail for each part of the system.

All equipment or components that are used on or around the bridge site must be carefully selected so that they do not detract from the aesthetic value of the bridge and are able to survive in a hostile environment, all the while providing acceptable levels of performance with minimum maintenance. These criteria prove to be the most important aspects of any equipment choice for most covered bridge applications. All components of the security system that are located on the bridge site should be weather resistant, resistant to the constant abuse of insects or animals, and be placed so that the components themselves are protected from vandalism. An in-depth look measures the need to protect equipment and is discussed in further detail in the set-up section of this report.

All the following equipment explanations are designed to be a brief overview and not a complete narrative. Multiple sources exist such as online reviews and other publications that can assist the security system designer when selecting equipment options based upon their abilities and limitations. Detailed communication with all equipment manufacturers can ensure that all devices can be integrated effectively and meet or exceed the requirements of the bridge owner.

Equipment Options

Each covered bridge is unique in its aesthetics, structural design, and surrounding landscape, so equipment may be listed here that would not be applicable to a specific bridge. The designer of the security system for a particular bridge should be sensible and rational about what pieces of equipment are selected. In later sections of this report, we discuss which systems might be best used for different locations and situations.

None of the equipment listed below is intended to be used stand-alone to protect a structure. Several pieces of equipment that work together to protect the bridge need to be integrated as efficiently as possible. The five areas of security that are listed by the BRP (i.e., deter, deny, detect, defend, and strengthen structure) cannot be obtained with a single piece of equipment. Any one piece of equipment may only provide one or possibly two types of security; therefore, to obtain optimal levels of security, it is essential to use multiple pieces of equipment that have multiple abilities, as shown in Figure 2.

A decision-making tool, shown in Figure 3, was created to aid bridge owners in making quick decisions about the type of security system to be installed on a particular bridge with a given budget. All prices are considered to be average and may be significantly higher or lower depending on the abilities of the equipment and the specific manufacturer. Each piece of equipment that is listed in this spreadsheet is expanded upon in this section with capabilities and limitations of all equipment.

Deterrence Equipment

Alarm System—Any of the above pieces of security equipment, either stand-alone or together in a system, are nothing more than hardware without the integration of a carefully designed alarm system. Chapter 104, Tyska and Fennelley

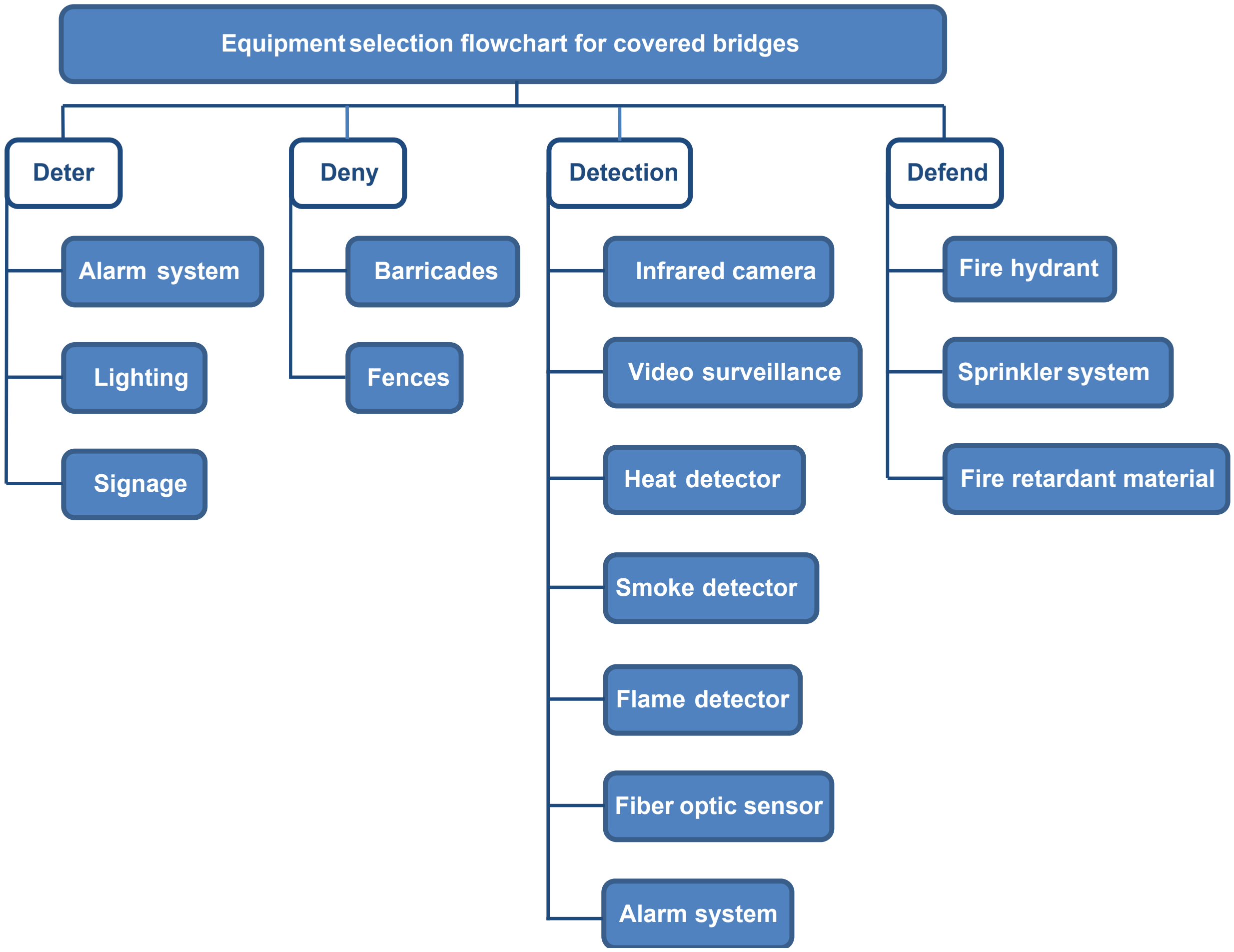

Figure 2. Flow chart of equipment options.

(2000) discusses alarm systems in great detail. Several different alarm systems may be used depending on the intent and level of security. The different types of systems can include alarms that silently send out an alarm to the proper authorities, a system that emits an audible alarm, some type of visual alarm in the area of the bridge, or a combination of the two. Several different issues may factor into the decision on what type of alarm system to use, such as the bridge's proximity to local authorities and residential areas. If the bridge is in close proximity to a residential area, it may not be attractive to have a loud, audible alarm that could disturb residents for all alarms, real and false. The proximity to the local authorities, and more specifically their response time, is also a key factor in the decision of the type of alarm system. If the bridge is within a reasonable distance to a fire department or police station, it may be more appropriate to have a silent alarm that will only alert the local authorities and give them the possibility of apprehending the criminal. If there is more considerable distance between the bridge and the local authorities or if the bridge is protected by a volunteer fire department, an audible alarm may alert both the criminal and nearby local public with the intent of deterring the criminal before more damage is inflicted to the structure.

A standard alarm system generally consists of the following:

- Detection elements located at the protected area, designed to initiate alarm upon entry of an intruder.
- Transmission lines that conduct signals to a device in the immediate area or to a central annunciator panel that can be continuously monitored.
- A panel that announces by visible or audible signals the structure or area in which an alarm has been activated.
- Fail-safe features that provide a signal at the annunciator panel if any part of the system is malfunctioning.

Lighting—Most vandalism and arson are committed during the nighttime hours because the trespassers are disguised by the darkness. Adequate lighting at the bridge site at all times can prove to a cost effective and efficient way of protecting the bridge. In Chapter 24, Tyska and Fennelley (2000) discuss lighting and note the importance of using the right amount of lighting that is effective yet does not contribute to

	Equipment	Average Price	****Threat Level	Average Capabilities	Main Drawbacks	*Requirements	Maintenance
Deter	**Alarm System**		MA/MV	Audible/Visible signals at structure Notify proper authorities	Possibility of false alarms at bride site Can notify trespasser and allow excape	Low electrical draw Enclosure for communication	Monthly
	Annunciator Panel	$300					
	Lighting	$70/fixture	MA/MV	Make portions of bridge site visible day/night Allow cameras to see during low light levels	Can lead to light pollution	Moderate electrical draw	Yearly
	Signage	$50	LA/LV	Inform trespassers of consequences			Rare
Deny	**Barricades**	$300	LA/MV	Limit traffic to certain sized vehicles Stop traffic altogether from entering bridge	May be difficult to move when necessary		Rare
	Decorative Planters	$300					Rare
	Bollards	$150					Rare
	Fences	$15/foot	LA/MV	Limit access points at bridge site	Cannot completely limit access points		Rare
	Chain Link	$8/foot					Rare
	Wood	$10/foot			Rot and warping of wood may occur over time		Yearly
	Wrough Iron	$25/foot					Rare
	Block Wall	**$10/SF					Rare
Detection	**Infrared Camera**	$5,000	HA/LV	Monitor temperatures within field of view View bridge regardless of amount of light	False alarms due to glare, animals, or heat Sensitive to environment	High electrical draw Pole	Yearly
	Video Surveillance	$300	LA/MV	View bridge during times of adequate light Allow remote parties to view bridge	Dependent on lighting in field of view	High electrical draw Pole	Yearly
	Heat Detector	$100	HA	Monitor temperatures around detector	False alarms due to environment	Moderate electrical draw	Yearly
	Smoke Detector	$50	MA	Monitor smoke levels around detector	Highly vulnerable to exterior conditions	Low electrical draw	Monthly
	Flame Detector	$1,500	HA/LV	Monitor temperatures within field of view	False alarms due to glare, animals, or heat	Moderate electrical draw	Yearly
	Fiber Optic Sensor		MA	Monitor temperatures along length of device	Possible difficult with installing	Moderate electrical draw	Yearly
Defend	**Fire Hydrant**	**$3,000	MA	Provide water source to fire department	Requires close water supply	Close water supply	Yearly
	Sprinkler System	**$15,000	HA	Extinguish fires started within interior of bridge	Requires close water supply Bulky and not aesthetically pleasing	Close water supply	Yearly
	Fire Retardant Material	$8/SF	HA	Stop or slow the ignition of a fire Stop the spread of any fires that may start	Loss of effectiveness over time Loss of structural strength to applied members		Every few years
	Intumescent Coating	$8/SF					
	Fire Retardant Wood	***%20 increase					

Notes:

* Draw requirements are as follow
    Low: 0.01 - 0.2 amps AC
    Moderate: 0.25 - 0.49 amps AC
    High: 0.5+ amps AC

** Includes installation

*** 20% increase from typical lumber used on covered brdges

****Protection from Different Threat Levels
    LV: Low Vandalism
    MV: Medium Vandalism
    HV: High Vandalism
    LA: Low Arson
    MA: Medium Arson
    HA: High Arson

Figure 3. Equipment selection tool.

any light pollution, which could be unattractive and costly. Many guidelines can be used to limit light pollution on the bridge site including the use of sensors, timers, high-efficiency fixtures, directional fixtures, and others. It may also be more economical in the long run for a professional with experience with exterior lighting to design the lighting system. Proper lighting can be used in unison with an optical camera to improve effectiveness. Multiple types of lighting can be used in a variety of situations. They include the following:

Perimeter Lighting: This type of lighting is used to illuminate the fence or perimeter of a certain site. The perimeter for covered bridge sites could be at a certain distance from the bridge or be the perimeter of the bridge itself. Perimeter lighting is used so that trespassers must pass through an adequately lit perimeter that may or may not be under surveillance. This is to act as a deterrent to the trespassers.

Area Lighting: This type of lighting is used to illuminate the area immediately surrounding the bridge that must be passed through to enter the bridge. Much like perimeter lighting, area lighting is used as a deterrent to trespassers by making it necessary for people to pass through brightly lit areas to reach the bridge.

Floodlighting: Floodlighting is used to saturate an entire area with bright lighting to deter trespassers. This type of lighting may detract from the aesthetics of the bridge and distract people driving by and living near the bridge site.

Gatehouse Lighting: This type of lighting illuminates entrances and exits to and from the site. This is essential for the entrances of both sides of the bridge as well as entrances to major roadways around the bridge site.

Signage—Placing signage around the entrances of the bridge site stating that anyone who enters after nightfall or attempts to deface the bridge will be prosecuted to the fullest extent of the law is an effective way of deterring trespassers. Signage stating that there is a surveillance system on site that is running 24 hours a day should also be considered for added deterrence. The more signage that is present on the site, the more likely it is that people entering the site will see it. In Chapter 89, Tyska and Fennelley (2000) discuss the usage of signage in great detail.

Deny Equipment

Barricades: In Chapter 4 of *Perimeter Security*, Michael Arata (2006) discusses barricades in full detail. Many covered bridges today are closed to motor vehicles to reduce live loads on the bridge. Barricades offer a variety of advantageous features. Foremost is that they make it difficult for trespassers to get too close to the bridge with motor vehicles. This is important, as this means that they must travel distances on foot, which may slow entry to the site, and more importantly, exit after a defacement has occurred. There are several different barrier options including natural and man-made styles.

Natural Barriers: The bridge owner does not have much influence on the types of natural barriers present at a given bridge site. In most cases, these types of barriers cannot be moved or changed in any major way because of physical limitations, aesthetics, or environmental regulations. Thus, the security system designer should seek to leverage the natural barriers to enhance the security at the site and minimize any negative influence they may have on the system. Many different types of natural barriers will be unique to every bridge site. Examples of possible natural barriers that may be present at any given site are as follows:

- Rivers—Many covered bridges were used to span over rivers, so this will be a typical natural barrier that will occur at many bridge sites unless the bridge was moved to a safer location. Rivers are an effective way of keeping trespassers away from the shielded and vulnerable underside of the bridge.
- Thick brush—Much like rivers, some covered bridges are in heavily forested areas where vegetation will be close to the bridge site. Some may consider this to be a nuisance, but thick brush can act as a natural barrier that will keep out motor vehicles and, in many cases, trespassers. The security system designer can choose to plant hedgerows in strategic areas to deny or deter trespassers from entering certain areas of the bridge including underneath the bridge itself.
- Mountains—Some bridges may be in mountainous areas where sheer rock walls or other features can be present around the bridge site. Sudden changes in elevation can aid the security system, as many trespassers would be deterred by having to climb a large shear wall or incline.

Man-Made Barriers: As mentioned earlier, several different options for barriers can be chosen by the security system designer. Some options may not be reasonable at all sites but some possible options for man-made barriers are as follows:

- Decorative planters—The use of decorative planters can take multiple shapes whether it is as a planter or a bench. The main advantage of using a decorative planter is that they are aesthetically pleasing and can be an efficient barrier. They will deter motor vehicles from entering the bridge site but can be temporarily moved by a forklift or other heavy machinery in the event that someone with authority needs to enter the bridge for maintenance or other legitimate reasons.

Figure 4. Typical bollards.

Figure 5. Standard K-rail (Permission to reprint given by Rob Vander Veen, Mid State Concrete Products, Santa Maria, CA).

- Bollards—A bollard is a cylindrical tube that is usually 12 to 24 in. in diameter and can have variable heights above the ground (Fig. 4). The many types of bollards include fixed, removable, and retractable, and they can be constructed from a wide range of materials including wood, concrete, steel, or plastic.
- K-rail—Also commonly known as a Jersey barriers because they were first used on the New Jersey Turnpike, K-rails are typically used to deflect motor vehicles safely. K-rails are sometimes viewed as not very aesthetically pleasing (Fig. 5).
- Welded steel guard rails—Much like the K-rail, the use of welded steel guardrails may not be the preferred choice because of its negative aesthetic value. Although it may have not been aesthetically pleasing, the use of steel guardrails is generally a low-cost and effective way to protect the entrance to bridges.
- Berms/ditches—One of the simplest ways of creating a barrier is to simply have a ditch or berm around an area that is off limits (as long as it does not create a hydraulic scour hazard). This may not be as effective as other means, as some motor vehicles may be able to navigate over or around a ditch or berm.

Fences: In Chapter 3 of *Perimeter Security*, Michael Arata (2006) discusses fences in full detail in the book. Fences at a bridge site would help to force the public to enter the bridge site through secure entrances that can be monitored and controlled. Fences should not be considered to be a way of completely preventing unwanted entry into a bridge site but rather a way of slowing down and deterring trespassers.

When deciding to build a fence, many decisions need to be made, depending on the type of bridge site that is being secured, including the following:

- Chain Link—Chain link fences are the most common type of perimeter fences because of their price, easy set-up, and low maintenance requirements. The chain link fence is so functional that the Federal government widely uses it and has the following specifications that can be found in Federal Standard RR-F-191/1A. The following is a summary of Federal specifications taken from the Defense Logistics Agency (DLAI 5710.1):

1. Fabric made of chain link
2. No. 9 gauge or heavier wire
3. Seven feet high
4. Fence fabric mounted on metal posts set in concrete
5. Mesh openings not larger than 2 in^2
6. Fence bottom within 2 in. of solid ground
7. Fence top guard strung with barbed wire, and angled outward and upward at a 45-degree angle
8. The fabric used for the chain link fence should be galvanized, aluminized, or plastic-coated woven steel. The fabric should be connected to the posts with the same gauge wire that the fabric itself is made out of. If a fabric is used that has openings larger than 2 in^2, then the fence itself will be much easier for intruders to climb and should be avoided when possible. The use of privacy slats are commonly used with chain link

fences but should be avoided on bridge sites as they allow intruders the ability to approach the fence without detection from the outside.

The Federal specifications are not required by bridge owners but are good guidelines for creating an effective perimeter. The use of barbed wire for extra security may not be required, as most bridge sites will not need this high level of security.

- Wrought Iron—The wrought iron fence is growing in popularity but is used mainly as an upgrade to chain link fences. Wrought iron fences are used commonly in residential areas as they are more decorative and aesthetically pleasing. The top of the fence is typically bent toward the outside of the area being contained with the ends sharpened for added security. It can be more difficult to climb a wrought iron fence than a chain link fence, especially a chain link fence without barbed wire, but the added cost of a wrought iron fence may be prohibitive.
- Wood—There are many options when using wood fences including design and level of security. Most wood fences do not allow a clear line of site to the other side of the fence, which is not desirable on a bridge site. With this lack of vision and the increase in maintenance required when compared with steel fences, wood fences are not typically a viable option for bridge sites.
- Concrete or Block Wall—Much like the wood fence, when using concrete or block walls many options can be considered as each wall is unique (e.g., type of block, color of block, type of foundation). Many concrete walls have barbed wire installed on top for added security, but this is not a requirement. Concrete or block walls will generally be significantly more expensive than a steel fence and will take longer to install.

Detection Equipment

Infrared Camera: An IR camera has the ability to detect and record the temperatures of different elements within its field of view during all times (e.g., during daytime and night time). This key attribute of IR cameras makes them especially attractive, as most acts of arson and vandalism occur during at night when the perpetrator can be masked by darkness. The major drawback for installing an IR camera at a bridge is the inherent cost when compared with other surveillance equipment.

IR cameras with appropriately configured software have the ability to detect motion and to issue alarms at certain temperature thresholds, and certain rates of temperature change. Great care should be taken when using a motion detection device of any type as large animals, such as deer or bears, could enter the field of view of the camera and set off the motion detector resulting in a false alarm. In general, however, these problems can be overcome by properly setting the "person" detection temperature threshold properly. Another threshold temperature setting issue relates to the type of wood preservative used on the bridge. Specifically, it has been observed that timber treated with creosote can get hot enough to approach flame temperatures and can thus cause false alarms.

As mentioned earlier, the main negative associated with IR cameras is the initial purchase price. Since IR camera technology is more advanced than other surveillance equipment, it might be more costly. As a result, the designer must consider if the advantages of deploying IR camera technology warrants the initial cost.

Typically, IR cameras are not built for exterior applications so it is important to include weather-resistant, protective housing for the cameras when estimating the system cost. Many such enclosures are offered by the IR camera manufacturer and can be custom made for any sort of application (including internal heating, internal cooling, etc.). Although the cost is high, it is still a valuable piece of equipment and was used on multiple case study bridges detailed later on in this report.

Video Surveillance—Video surveillance equipment is viable for monitoring bridge activity during the daytime or if the bridge is adequately lit during nighttime hours. It is important to know the technical abilities required of the camera and to choose a camera that will meet or exceed the expectations. The price for a common video surveillance camera is quite low and it may prove appropriate to place multiple cameras around a site.

Some cameras have the ability to change from infrared to visible light depending on the level of light in its vicinity. These cameras may be a more economical decision than buying them both separately. There are several manufacturers of cameras for adverse exterior conditions that range in ability and price. It is important to work with the manufacturer to select the appropriate camera for the bridge site in question. Much like the IR camera, the video surveillance camera must be located in a tamper resistant and environmentally appropriate housing.

Heat Detector—Several different types of heat detectors can be selected for bridge security. The two most common heat detectors commercially available are the fixed temperature and the rate of rise heat detectors. The fixed temperature heat detector is set to sound an alarm once a predetermined temperature has been reached. A rate of rise heat detector will set off any alarm once a certain rate of temperature gain has been reached. Both the predetermined temperature and rate of rise can be adjusted. In many ways, these settings are relatively the same as the IR camera thresholds mentioned earlier.

Note that the rate of rise heat detector may be more vulnerable to false alarms within the given environment. Specifically, covered bridges may be susceptible to sudden increases in temperatures, such as being warmed by the sun or a piece of machinery operating next to or on bridges that are still open to traffic. With these conditions being present on most covered bridges, it is important to place heat detectors out of direct sunlight. Some possible places to put these devices would be underneath the wooden deck or underneath the rafters on the top portion of the bridge.

Smoke Detector—A smoke detector may assist with fire protection coverage on a covered bridge; however, it may have a higher source of false alarms because the smoke detector will have to be placed within the covered bridge to be effective and will be vulnerable to dust and other debris coming in contact with it. In general, most smoke detectors are not designed to operate outdoors and special care must be given if a bridge owner wishes to deploy such a monitoring device.

Flame Detector—A flame detector may be one of the more important pieces of equipment in a set-up for security of covered bridges. The flame detector may be placed within the bridge interior where it will be able to view a large portion of the bridge. If necessary, multiple flame detectors may be used together in a system to optimize coverage of the bridge. Most flame detectors have a mechanism that significantly reduces false alarms

In general, flame detectors rely upon multiple measurements to determine if a fire has been set. First, and probably most obviously, flame detectors detect heat and are generally preprogrammed to know typical flame temperatures. Further, flame detectors typically have a sensing component that detects the unique flicker rate of flames. These redundant systems tend to reduce the number of false alarms that occur.

Fiber Optic Sensor—Fiber optic sensors may be used to measure rotation, acceleration, electric and magnetic field measurement, temperature, pressure, acoustics, vibration, linear and angular position, strain, humidity, viscosity, chemical measurement, and a host of other sensor applications not mentioned here. The fiber optic sensors typically used for bridge security measure changes in temperature along the length of the bridge. The main advantage of these sensors is that they have good bandwidth size and are lightweight, small, passive, resistant to electromagnetic interference, highly sensitive, and durable.

Many different types of fiber optic cables vary in price and it is important to choose a cable that can survive in the adverse exterior conditions where many of the bridges are located. The cost of fiber optic cables can be very cheap when compared with other equipment, and the cost continues to go down as the technology improves. However, the hardware required to read the fiber optic sensors tends to be quite expensive.

Defend Equipment

Fire Hydrant—One portion of fire protection that could easily be overlooked is how the fire will be extinguished. Fire trucks can store their own water and some even have the capability of pumping water from sources such as nearby rivers and lakes. However, in some cases the water source is too far below the elevation of the road to allow pumping. In this case, an additional pump at the water may be necessary to aid the fire truck in pumping the water up to the road elevation. It is important to know the limitations and abilities of the fire department that provides service to the covered bridge of interest.

If a municipal source exists near the structure, fire hydrants should be located on both sides of the bridge placed at a far enough standoff distance that heat from a bridge fire would not impede fire fighters hooking up hoses. If it is uneconomical to connect to the municipal water source because of the isolated condition of the covered bridge, it may be plausible to install a dry fire hydrant by connection to a water source nearby, as mentioned above.

Sprinkler System—If a fire of considerable size has been established before the fire department can arrive at the bridge, the center of the bridge may be inaccessible to fire personnel. This is a major problem for the structural integrity of the bridge, as this is where some of the largest forces exist. This problem can be solved by the installation of sprinkler systems within the center portion of the bridge or along the entire length of the bridge. It is essential that the sprinkler system selected be a dry pipe system so that freezing and bursting pipes do not become a problem during inclement weather. A dry pipe system has no water in the pipes until a sprinkler head is set off, at which point water enters the system and extinguishes the flames.

The first question the bridge owner would ask when discussing the possibility of installing a sprinkler system is the aesthetic effect on the bridge. As most sprinkler systems are relatively bulky and unattractive, it is important to place them in inconspicuous areas that are not seen by the public. The most economical and effective areas to place the sprinkler systems would be running underneath the bridge with the flow pointing upward toward the bridge deck and above the roofing members with the direction of the flow pointing down and to the sides. This will provide the greatest bridge coverage for most bridge applications.

Fire-Retardant Material—Achim Hering (2001) gives us insight on fire-retardant materials in *The Proof Is in the Fire.* One of the most common types of security measures taken by covered bridge owners is to increase the fire resistance of the bridge. This is due to the cost efficiency of the material when compared with the level of protection added to the bridge. This can come in the form of some sort of coating such as intumescent coating or using fire-retardant wood when rehabilitating or repairing a bridge. This falls under the category of structural strengthening and will help the bridge stay structurally sound during the course of a fire before it is able to be extinguished. Using fire-retardant materials should not be seen as a final solution for bridge security because they do not stop the initiation of a fire but slow the progress of a fire such that major damage can be avoided. The application of a fire-retardant material to structural elements that are essential to the survival to the bridge is one of the most desired actions with bridge security related to fires.

Many of the lighter bridge elements such as shingles, siding, and any thinner wooden framing should be considered when deciding what needs to be treated with fire-retardant materials. These thinner pieces can be ignited much easier than the larger structural members such as the bridge deck and primary truss members. These thinner bridge elements can be the fuel required to ignite the larger members and cause serious structural damage in the case of a long-burning fire. Although it may be more economical and efficient to make the thinner elements fire retardant, it is not uncommon to make the entire structure fire retardant for an added level of fire safety. The cost should be weighed against the advantage of such an extensive procedure.

***Intumescent Coating*—**One of the more common fire-retardant materials used for covered bridges is intumescent coating. Intumescent coating is a thin layer of material very similar to paint in method of application as well as aesthetics and texture. It can come in a variety of colors including clear and semi-clear. There are multiple manufacturers of intumescent coatings and similar materials that can match the exact color scheme of any bridge so this coating can be applied to existing or new bridges.

The way intumescent coating works is by swelling when exposed to a certain level of heat that would be seen during the course of a fire. The chemically bound water in the coating absorbs heat, making it ideal for fireproofing applications. Intumescent coatings are used to keep the fire in the location of its origin instead of spreading. This type of coating will only become active after being exposed to heat. Although the coating of essential structural members is the most important, it is also beneficial to coat the entire bridge including siding, roofing, and all framing.

Although this is a very effective method of making a structure more fire resistant, it still has several drawbacks that must be considered for optimum protection. Much like any coating, intumescent coating will break down and become less effective over time and will need touch ups every few years and possibly an entirely new coat after multiple touch ups. These times are dependent on the conditions at the bridge site including humidity, direct sunlight, and temperature changes. Different manufacturers will have different materials that will be adaptable to different conditions so it is important to choose the correct coating for an exact bridge location.

***Fire-Retardant Wood*—**Robert Durfee (2003) has an extensive section on fire-retardant wood in his article, "Vermont's Covered Bridges." Fire-retardant wood is created by pressure-treating the wood with a fire-retardant chemical. Multiple manufacturers of fire-retardant materials use different chemicals and have differing levels of fire resistance. Most fire-retardant woods are designed to not light on fire even with direct contact with a flame or the fire will not spread after it is initially lit.

A major drawback to using fire-retardant wood is the decrease in the structural strength of the member by up to 10% to 20% depending on the exact type of chemical used. This can become a major issue if fire-retardant wood is used on structural members such as the bridge deck, as the members may need to be larger since they will have decreased strength. Much like the intumescent coating, there is a decline in the effectiveness of fire-retardant wood that is accelerated from being in a harsh exterior location. This decline in effectiveness can be slowed substantially by painting the wood soon after installing it.

Pole Placement

Most security systems, especially those involving cameras, will be required to have a pole or pedestal of some kind for placement of the necessary security monitoring hardware. Below are some of the key factors to consider when selecting a pole type and location.

Aesthetics

The pole placement will ultimately be a decision directed by owner of the bridge and the security system designer. The most important factor influencing the final placement of the pole will be the aesthetic effect on the area surrounding the bridge while at the same time being placed so that adequate coverage is achieved. Because covered bridges can be a major source of tourism for smaller towns around the United States, it is important that the security systems installed do not draw attention away from the bridge and the surrounding landscape. Depending on the landscape and surroundings, this may be detrimental to the effectiveness of the security system because this usually requires that the pole be placed a large distance away from the bridge. An ideal situation at the bridge location would be a pre-existing pole such as a light pole or power line pole that, upon approval of the owner, could double as the mounting pole.

The type of material used for the pole is mostly an aesthetic decision. Several different types of materials can be used for the pole such as metal, concrete, or wood. To blend in with the surrounding area, we suggest that a survey be taken of what is around the possible pole location to see if other light or electrical poles are within sight. If other poles are in the surrounding area, it would be preferable to use the same type of material and pole height to let the security pole blend into its surroundings.

Line of Site—Even if a pole is within a reasonable distance from the bridge, it must be guaranteed that there is a direct line of sight to both the front and rear entrances to the bridge to allow the system to be as efficient as possible. Even if there is a direct line of sight at the moment that the security system is enabled, it is important to look for possible obstructions in the future such as trees or other vegetation that could have the potential to grow or move into the direct line of sight. Any potential problems should be dealt with as soon as possible to avoid costly problems in the future.

It may be possible to only allow a direct line of site to one entrance of the bridge because of environmental constraints. If the designer has the ability to use a pole facing toward either entrance of the bridge, many criteria must be considered. If the bridge is closed to vehicle traffic, then the entrance that will see the greatest amount of pedestrians would likely allow for the greatest amount of security on the bridge. The ease of connecting to electrical power should also be considered if electronic equipment will be used in the security system.

Functionality—Placing the pole at a significant distance from the bridge creates multiple problems, and there must be a compromise between aesthetics and functionality to make the pole as practical as possible while still keeping its presence as benign as possible. The two major problems with placing the pole at a significant distance from the bridge come from the effectiveness of the cameras and problems associated with running the wire over long distances. Both of these problems can be solved by using more sophisticated equipment; however, doing so directly correlates to an increased cost for the project.

A camera is still effective in generating a clear and usable image at differing ranges. These ranges will obviously change with differing manufacturers and cameras, and it is important to be cognizant of all camera specifications to ensure that all limitations at a certain bridge are overcome by the camera selected. This is applicable to all cameras used on the bridge including infrared or optical cameras.

The other problem that results from a greater pole distance is functionality losses within the wires that must be run from the pole to the bridge. Although this particular problem will not usually be a critical problem with the security system design, it needs to be considered before placing the system in the field to ensure that the proper power is reaching the systems. If this is done, the system will operate as expected and will result in fewer maintenance issues in future. If major problems with power loss occur across the wire between the bridge and the pole, several different solutions could be applicable, depending on the amount of power loss. One solution could be to use a wire with a higher conductivity so there would be less loss. Another solution could be to use a higher source of power that will overcompensate for the loss across the wire.

It may desirable to the owner to use the pole for other functions outside of security reasons. These other functions could include placing a street light on the top of the pole to provide lighting for the surrounding area. This could also be considered a security device, as well-lit areas are less likely to have trespassers that could potentially cause harm to the bridge. It is important that the street light does not cause the area to be over lit, which could cause light pollution and take away from the aesthetic value of the surrounding area.

Enclosure Selection

Depending on the functionality of the security system, varying amounts and types of equipment that because of their design, construction, and cost will need to be housed in a secure location that will also protect them from weather. Several methods can achieve this, and much like the selection of all the other aforementioned components, several factors should be considered in the selection of the appropriate enclosure.

Types of Enclosures

Standard Box—A metal box will prove to be efficient for many bridge sites, as many pieces of electrical equipment require small components for power and storage of data. If cameras are used as part of the integrated security system on the bridge site, a small box could easily fit on the pole itself where all the cameras are located. If a pole is not available, a box may be positioned on some sort of pedestal to allow the box to be safely lifted off the ground as to deter any water, insects, or animals from attempting to enter the box.

NEMA Enclosures: It is generally suggested that all enclosures meet a certain standard set by National Electrical Manufacturer's Association (NEMA), and for most applications with these systems the owner should require at least a NEMA 4, 4X, 6, 6P. The technical explanations of the exact NEMA standards are as follows:

- Type 4—Computer enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt, rain, sleet, snow, windblown dust, splashing water, and hose-directed water; and that will be undamaged by the external formation of ice on the enclosure.
- Type 4X—Protection unit constructed for either indoor or outdoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt, rain, sleet, snow, windblown dust, splashing water, hose-directed water, and corrosion; and that will be undamaged by the external formation of ice on the enclosure.

- Type 6PC—Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt; to protect against hose-directed water and the entry of water during occasional temporary submersion at a limited depth; and that will be undamaged by the external formation of ice on the enclosure.
- Type 6P—Cabinet constructed for either indoor or outdoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt; to protect against hose-directed water and the entry of water during prolonged submersion at a limited depth; and that will be undamaged by the external formation of ice on the enclosure.
- For most scenarios, a NEMA 4 enclosure will protect the electrical components against the elements as submersion under water will not applicable to most bridge sites and the added cost of higher levels of protection will not be required nor warranted. If water coming from multiple directions is a problem for a bridge, then a NEMA 4X enclosure should be considered

Structure—Some bridge locations will already have a small mechanical shed or other enclosed structure on site. This could prove to be advantageous for the security system designer for its ability to house the mechanical equipment that is required for running a security system. Depending on the size and scope of the security system to be installed, it may or may not be economically viable to construct a new structure on the bridge site to house the mechanical equipment when compared with a box that could be attached to a pole or pedestal as mentioned earlier.

Aesthetics: The selection of the enclosure to house all of the electrical components of the security system is comparable to the selection of the pole. The box must not have a large aesthetic impact on the surrounding area but must maintain functionality. Most box set ups that are available to the owner will be constructed of metal and will have a grey or metal color to them. It is possible, and in many applications preferred, to paint the box to match the surrounding area.

Functionality: Once the design team has decided upon the exact NEMA type of enclosure that will be used for the project, it is important to decide on the exact dimensions of the box. This can be accomplished by taking all the equipment that will be placed inside the box such as modems, computers, power strips, and any other sensitive equipment that needs to be secured in a weather-tight enclosure. Once the team has a list of all the equipment that needs to fit into the box, it is important to draw a schematic of how everything will fit. Once a rough layout is available, take into consideration how many outlets will be needed to power all the equipment and exactly what type of power strip will be used. Once all this information is available, the team will have a rough idea of the size of the box. It is important to order a box that is larger than exactly what is needed for minor equipment changes, cords, and future expansion.

It is important to understand that the heat that will be generated from the electrical devices within the box will be exaggerated by the temperature outside of the box in summer. The temperature within the box can easily become hot enough to overheat the electrical components and shut off the entire security system. Purchasing a box that has a fan or louvers to allow air circulation will add cost to the project but will allow the security system to operate through even the hottest months. After-market fans and louvers are available to install on boxes that do not have adequate ventilation. It is essential that any openings in the box protect the components inside from water or insects entering and potentially destroying the electrical components.

Power Considerations

The remote locations of many covered bridges within the United States often make it difficult or expensive to gain access to electricity to power the security system. The distance between the closest grid power and the location of the bridge may sometimes be so great that running a power line to the bridge is not cost effective. If grid power is not an economical option, different types and combinations of renewable energy sources may meet the needs of the system. Renewable energy will be discussed in full detail later on this section of the report.

Grid Power

If a hook up to grid power is readily available and economically viable, it will typically be the best choice as it will be the most dependable source of electricity. It is important to have a constant source of power with any security system to ensure that it works with the least amount of down time. The only problem with grid power is the reoccurring cost from the local electric company for using their services. Given that the draw from a typical security system is relatively small, the charges will also generally be minimal.

Renewable Energy

It is prudent to consider using multiple sources of renewable energy when setting up this type of system because any one source will not be consistent at different periods of time. Wind power only works when a substantial wind is occurring and solar power will only generate electricity during daylight hours, with energy output varying with the intensity of the sunlight. By using both systems, you will increase the

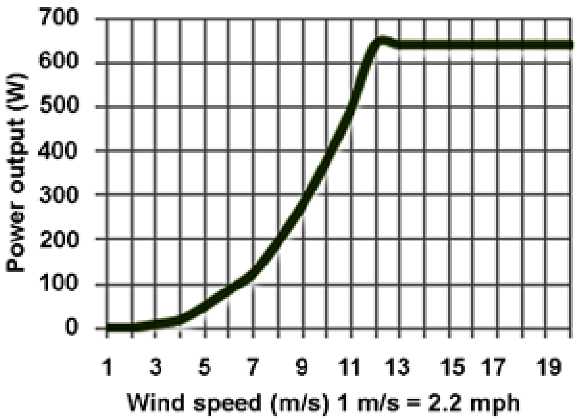

Figure 6. Wind speed to power output graph for 600-watt wind turbine. Source: Urban Green Energy 600-watt wind turbine specifications. Urban Green Energy Inc., New York.

chances that one of the sources will be generating enough electricity for the security system. For times when not enough power is being generated, batteries must be used to store electricity if grid power is not available. It is possible, however, that one source of power will suffice if the draw from an individual security system is relatively small and the battery bank is relatively large and can provide adequate reserve power.

Using renewable energy to power a security system is a large undertaking and should be thoroughly considered before and during design. Compared with a direct city link for electricity, a renewable energy system will require notably more planning, maintenance, up-front cost, and patience. This fee will not occur with the use of renewable energy sources, but a city hook-up will not have the large up-front cost associated with setting up a renewable energy system.

Some systems may elect to use both grid power and a renewable energy system. A system of this type will use renewable energy whenever it is generated and use the grid as a backup if the renewable energy sources stop producing energy. By using this type of system, you can also use energy that is generated and stored. Some electric companies will allow you to generate electricity for them and will pay you incentives to do so. These incentives have the possibility of paying back the fee associated with using the grid power and possibly even pay for the security system itself.

Multiple types of renewable energy systems currently exist and several other sources are on the horizon. Although multiple sources of alternative energy exist, only a few will be useful at most covered bridges sites given their isolated locations and natural surroundings. The only sources of alternative energy that will discussed within this report are wind and solar power, as these are the two sources that will likely be present at most covered bridge sites.

Wind—Blades of a wind turbine harness energy from the wind and turn it into electricity through the movement of the blades. Ideally, a wind turbine should be placed in an area that has constant, nonturbulent wind. We recommend that the wind turbine be placed at least 30 ft above the ground and 300 ft away from all obstructions that could cause turbulent wind (e.g., structures, trees, changes in terrain). These distances are only recommendations and may be shortened, but optimal performance of your wind energy system will be at distances that equal or exceed these recommendations. Different companies may have different recommendations for placement of their particular wind turbines, and it is important to follow them as closely as possible to get the maximum efficiency from the equipment.

In general, the more power required from a wind turbine, the greater the blade diameter required. The blade diameter often becomes a limiting factor when designing a hybrid energy source depending on what is allowed by city ordinances and historic structure limitations. It is important to realize that the wind turbine will be placed within close proximity to a covered bridge that is a draw for tourism and the local economy, so care must be taken to not detract from the aesthetics of the surrounding area.

When sizing the wind turbine for a particular security system, it is important to realize that the rated output for the turbine is for the optimum wind speed, which will not be the average wind speed in many instances. These speeds can meet or exceed 20 to 30 miles per hour with most types of wind turbines, which is not a constant wind speed in most areas. It is important to review and consider the wind speed-to-power output graph that is supplied with most turbines to choose the correct equipment that will produce the proper power output at average wind speeds at the bridge site. Figure 6 shows a wind speed to power output graph for a 600-watt wind turbine and shows that it will only produce 600 watts of power if the wind speed meets or exceeds 26.4 mph. This power curve has been measured under laminar wind conditions with the load connected directly to the generator.

For security systems with "lower" power requirements, 100 to 10,000 watts, there are two main types of wind turbines that should be able to produce the needed power: the horizontal axis wind turbine and the vertical axis wind turbine. Each type of wind turbine has its distinct advantages and disadvantages and there must be a benefit/cost analysis done to consider price, efficiency, and power output for the type of power output needed for a particular security system. The vertical axis turbines are well suited for smaller applications such as a security system and can survive wind gusts better than most horizontal wind turbines. It is important to discuss with the manufacturer the exact requirements needed for the security system and the environment where it will be installed.

Solar—Solar panels harness the sun's energy and efficiently convert it to electricity. Solar panels continue to become more efficient as the technology improves, making them smaller and more efficient; that said, size is still a main factor in the selection of a solar power system. Current technology allows 10 watts per square foot of solar panel according to top solar companies available for distribution in the United States (Anon 2011). Some panels will give you more or less wattage per square foot depending on price and the advancements in technology within the company. It is important to realize that an increase in efficiency will generally relate to an increase in price.

Although solar power can be an efficient source of renewable energy, it should not be thought of being without limitations. Because most security systems will need to be functional at all hours of the day, it is essential that a constant source of power is available day and night. Therefore, because solar power is only available during the day, it is essential to incorporate an adequately sized battery bank and potentially couple it with wind power or grid power to allow for uninterrupted power day and night.

Battery Bank—Batteries are important for any renewable power source system for moments when not enough sun or wind can generate the power needed to run the monitoring equipment. To design the proper battery bank for your system, it is important to know the power draw of your security system at peak performance, average hours of sunlight in your area, and the average wind speed in your area. Most renewable energy companies will be able to help you estimate the natural conditions at the bridge site depending on which part of the country the bridge is located. There are also multiple resources online with this information.

Batteries are designed specifically for renewable energy sources, but marine or deep cycle batteries are also quite effective if designed and sized properly. Because the system will create a steady draw from the batteries even though the batteries will not get a consistent charge, it must ensure that the batteries will not fall below 50% of their amp hour capacity so no damage occurs to the batteries. Once batteries have fallen below a certain percentage of their amp hours, they may not be able to become fully charged with the aid of a renewable energy system.

Inverter—The inverter converts the DC power created by the renewable energy sources into usable AC power. Two main types of inverters can be used for this application: the pure sine wave and a modified sine wave. A modified sine wave inverter is less expensive but does not produce the type of power required by sensitive equipment. Pure sine wave inverters are more expensive but are the appropriate choice for this application. Much like the solar panels and wind turbines, the inverter is not 100% efficient, so it will be required to increase the power supply to compensate for this loss across the inverter. It is important to research different companies that produce pure sine wave inverters and purchase one that meets or exceeds the requirements for the particular security system.

Controller—A renewable energy source will continue to charge the batteries indiscriminately if left unattended, which may overcharge the batteries and potentially damage them. Therefore, a charge controller is necessary to monitor the level of charge of the battery bank and manipulate the level of charge to the battery as needed. There are as many types of controllers as there are renewable power sources, so it is essential that a manufacturer's specification meet or exceed the requirements of the power system installed.

Set-Up

Several important steps are associated with set-up of the security system to ensure that it is aesthetically pleasing and functional. Although many of the major pieces of equipment have been discussed in great detail in previous chapters, it is important to have an understanding of all auxiliary equipment and components that are required to make the entire system functional. These materials include the type of conduit, wires, encasements, and the equipment to attach the box to the poll. More equipment may be required for a particular security system, depending on the location and type of system that will installed.

Conduit

To prolong the life of all wires and equipment, it is important to use conduit to run wires whenever possible. Several types of conduit could be used, including PVC, metal, or plastic. The design team should run an economic analysis deciding how vulnerable the wires are underground and how much each type of available conduit costs. It is important to choose a safe option that will adequately protect all the equipment, but it isn't necessary to always choose the strongest alternative. All conduit should meet or exceed all fire and electrical codes in the area of installation. The conduit should also be strong enough to protect against animals or insects penetrating the conduit and destroying the wiring.

Wiring

Wires come in a variety of sizes and types that range in price and functionality. These two main properties of wire are two of the biggest decisions when deciding on what type of wire should be used for any particular piece of equipment. Some equipment will have a minimum requirement for wire size to reduce resistance and improve the functionality of the piece of equipment itself. Table 2 demonstrates that as the gauge number of wire decreases, the diameter increases and the resistance decreases. A decrease in wire gauge will also lead to an increase in price per length, so it is not always practical to use the smallest gauge wire to increase functionality unless it is economically viable. If there is considerable distance between the equipment and from the power source,

Table 2. American Wire Gauge (AWG) chart for diameter, area, and resistance

AWG	Diameter (mm)	Cross sectional area (mm^2)[a]	Resistance (ohm/m)
0000	11.7	107.0	0.000161
000	10.4	85.0	0.000203
00	9.26	67.4	0.000256
0	8.25	53.5	0.000323
1	7.35	42.2	0.000407
2	6.54	33.6	0.000513
3	5.83	26.7	0.000647
4	5.19	21.2	0.000815
5	4.62	16.8	0.00103
6	4.11	13.3	0.00130
7	3.67	10.6	0.00163
8	3.26	8.35	0.00206
9	2.91	6.62	0.00260
10	2.59	5.27	0.00328
11	2.30	4.15	0.00413
12	2.05	3.31	0.00521
13	1.83	2.63	0.00657
14	1.63	2.08	0.00829
15	1.45	1.65	0.0104
16	1.29	1.31	0.0132
17	1.15	1.04	0.0166
18	1.02	0.82	0.0210
19	0.91	0.6530	0.0264
20	0.81	0.5190	0.0333
21	0.72	0.4120	0.0420
22	0.64	0.3250	0.0530
23	0.57	0.2590	0.0668
24	0.51	0.2050	0.0842
25	0.45	0.1630	0.106
26	0.40	0.1280	0.134
27	0.36	0.1020	0.169
28	0.32	0.0804	0.213
29	0.29	0.0646	0.268
30	0.25	0.0503	0.339
31	0.23	0.0415	0.427
32	0.20	0.0314	0.538
33	0.18	0.0254	0.679
34	0.16	0.0201	0.856
35	0.14	0.0154	1.08
36	0.13	0.0133	1.36
37	0.11	0.0095	1.72
38	0.10	0.0078	2.16
39	0.09	0.0064	2.73
40	0.08	0.0050	3.44

[a] Resistance of copper at 20 °C.

then a decrease in wire size may be required to reach an acceptable level of functionality.

Conduit can be easily used for running wire for certain applications such as underground or up a pole, but it may be difficult to use conduit within the bridge structure itself. All wire that is run without conduit should have a covering that can ensure proper protection. Within the bridge itself may be the possible threat of insects and small animals such as rats, birds, and squirrels; it is essential that all wiring be adequately covered to ensure that the wildlife will not be able to penetrate the coverings.

Attachment Devices

All equipment must be attached to either the bridge or other surrounding structures including poles or other structures. It is essential that all equipment is attached as securely as possible with a minimum of disturbance; this is especially true within the bridge structure itself. Many covered bridges have existed for over 100 years and it is critical that the security system being installed does not change the original design or construction of the covered bridge to preserve the historic significance of the bridge. If large alterations are completed on the bridge, it is possible that the bridge may not be eligible to be placed on the Register of Historic Places as mentioned earlier on in this report. Whenever screws or other attachment devices penetrate into the existing bridge, it is important to use the smallest size possible to minimize the permanent damage to the bridge.

Encasements

When ordering the equipment for a particular security system, it is important to notice the ability of the equipment to handle an outdoor atmosphere. Some types of equipment will be designated for indoor-only applications unless certain guidelines are met, such as the use of watertight enclosures. This is an often overlooked part of the security system but is important to the longevity of the system. Some proprietary systems will have casements for their products to protect them from exterior exposure while others may require the use of another system.

Some encasements may also be used in certain applications to increase aesthetic value of the equipment. These types of encasements may appear in the form as a wooden box around the equipment to give the appearance of a bird house, as seen in Figure 7. By using the same wood as the surrounding bridge, the flame detector shown in Figure 8 is not as aesthetically distracting as it is without the use of an encasement system. The simple act of painting the existing encasement of equipment to match its surroundings can be beneficial and will not detract from its aesthetic effect.

Supplementary Equipment

For any security system involving electronic components, it will be required to have supplementary equipment so that all components can operate efficiently. As mentioned earlier, it is important that someone knowledgeable about security systems, such as an IT professional, assists in the installation of all electronic equipment. Most electronic equipment will have software that may require manipulation to have the most efficient settings possible.

Communication Devices

It will be desirable for some information recorded at the bridge sites to be sent to a remote destination through the

Figure 7. Flame detector in covered bridge without encasement (top) and with encasement (bottom).

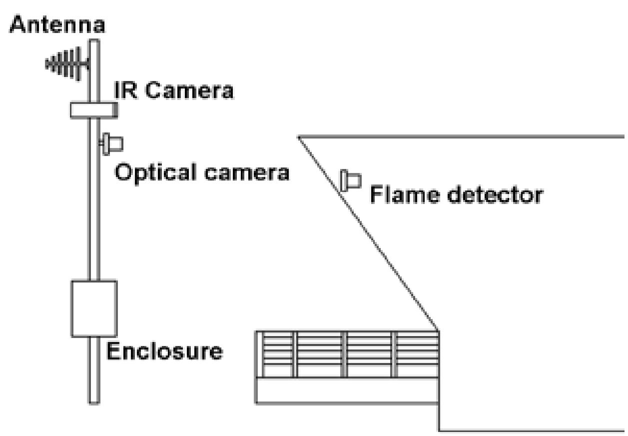

Figure 8. Cameras, antenna, and enclosure schematic at bridge site.

use of communication devices. The information recorded by the monitoring systems will prove to be useless if they cannot be seen by others at remote locations such as local fire departments or police stations. There are multiple ways of transferring this information to outside sources, but for more bridge sites, the use of directional antennas to access wireless connections will be the best option. Directional antennas allow for optimum signal in areas where cellular coverage may be low, which is typical in some isolated covered bridge locations.

Storage Devices

It will be important that some data are stored at the bridge site if not all information is sent to a remote location. Depending on the abilities of the communication devices selected, it may not be possible to send all information required through wireless sources. A storage device can be as simple as a desktop computer or can be much more complex with secure electronic storage cabinets that can be found through multiple manufacturers. It will not be cost-effective in most applications to store all information that is recorded at the bridge site but to only record certain information. This can include certain time periods after an alarm has been set off or during certain times of the day.

Software

Numerous software options are available for designing a monitoring system on a covered bridge. Some of these software options may be proprietary depending on the piece of monitoring equipment that is selected by the design team. For the system to be as effective as possible, it is essential that the correct software is chosen and the correct settings are selected within the software. In-depth software analysis is not discussed in further detail within this report because of the numerous options available. It is important to work with the manufacturer of the monitoring equipment to allow for optimum efficiency from all equipment within the system.

Testing

Testing is one of the most important aspects of creating an effective security system. All components should be able to fulfill or exceed their individual assignments, and the security system as a whole should be able to achieve a high level of security for the bridge as a whole. It should be stated that all fire testing, both in the lab and especially in the field, should be conducted in the safest possible fashion to ensure that there is no damage to any personnel, equipment, or property.

In-House Testing

It is crucial that all individual components of the security system are tested in-house before they are installed and tested at the bridge site. It is easier to troubleshoot equipment that is not working properly in an easily accessible, controlled atmosphere as compared with the bridge site, which may have inclement weather and equipment in hard-to-reach areas. Not only should the individual components be tested individually but the entire systems should be tested together to ensure that all parts of the system work together to reach the end goal of adequate protection of the bridge site.

In-Field Testing

As mentioned before, testing in the field should be conducted in the safest possible fashion. Before creating an open flame around, on, or within the covered bridge itself, it is essential that all proper officials are notified to avoid any problems with passersby from reporting the testing crew. Once all officials have been notified that fires will be started on the bridge site, it is essential that safety precautions such as fire extinguishers and buckets of water are on hand and close by in case a fire gets out of control.

Different equipment will have different thresholds at which they will be set off and trip an alarm. A typical fire for a flame detector may be a 1-ft by 1-ft^2 fire from a distance of 60 to 70 ft. This can easily be simulated by placing an adequately sized fire proof pan on a cart so it can be pushed around the bridge to ensure that all areas of the bridge are secure. This is essential to ensure that all cameras and detectors are pointing in the most efficient direction, and any adjustments can be made before the system is considered fully operational.

Infrared or other types of cameras may be motion detectors or be set to a certain temperature threshold. These should be tested at night when they would normally be operational and monitoring the bridge site. A fire may be started at one of the openings or inside the bridge within the line of sight of the cameras to ensure that the entrances of the bridges are secure from trespassers.

Summary

Covered bridges are an important part of history of the United States and must be maintained for future generations. Unfortunately, these bridges are being destroyed at an alarming rate from arson, vandalism, and neglect. It is essential that covered bridge owners know the importance of maintaining the structural and aesthetic integrity of their bridges. As stated earlier in this report, The FHWA Blue Ribbon Panel Workshop on Bridge Security Assessments has decided on five different levels of security to construct an effective defense against unwanted activities. These levels of security include deter, deny, detect, defend, and strengthen structures. The five parts of the security plan proposed by the BRP are equally important if implemented correctly. This report has taken an in-depth look at the different security and monitoring equipment that can be used at covered bridge sites.

What These Levels of Bridge Security Hope to Accomplish

Bridge owners that implement the levels of security discussed in this report should not expect their bridges to be indestructible but must realize that this increased level for security will greatly improve the chances that the bridge will survive for generations to come. It is impossible to make a structure perfectly secure but it is the responsibility of the bridge owners to make the structure as secure as possible within the economic and aesthetic limits of the bridge site and the financial situation of the bridge owner. As mentioned numerous times throughout this report, it is essential that all levels of bridge security are covered.

Maintenance

The implementation of these security and monitoring devices should not be considered the end of any security project. Constant monitoring of all equipment and periodic maintenance of both the equipment and the bridge itself are vital to the survival of the system and the bridge. It may be required to renovate the bridge both aesthetically and structurally throughout its life and both of these issues are discussed briefly in the recommendations portion of this report and also in great detail in *Covered Bridge Manual* by Phillip Pierce. Within years or even months, a monitoring or security system can prove to be obsolete and may not be able to fulfill its initial requirements.

Recommendations

Protection against arson and vandalism alone will not ensure the safety and longevity of the Nation's covered bridges. Other preventative measures must be taken as often as possible so the bridges do not succumb to other natural or manmade disasters. There is extensive coverage on the types of preventative measures that should be taken with historic covered bridges in the Federal Highway Administration Covered Bridge Manual published in April 2005 in Chapter 17, "Preserving Existing Covered Bridges." Topics included in this report are controlling water runoff, roof and siding protection, foundation support, regular cleaning, and fire protection. The FHWA report goes into other preventative measures for covered bridges (Pierce and others 2005).

When an extensive search for security and monitoring systems on covered bridges through the United States was conducted, we found that the most-used type of protection for covered bridges was the use of flame-resistant materials. These types of products tend to have a low cost for how effective they can be and may only need maintenance every 5 to 10 years. Most covered bridge owners may not have large sources of funding and a large scale monitoring system may not be financially reasonable. Bridge owners may also have difficulty with the heavy amount of maintenance that may be required for some monitoring or security systems.

Education

Physical protection is not always enough when it comes to the preservation of our national historic landmarks. Education can be an important tool when it comes to preservation. Integrating covered bridges into the school system can teach the importance of these structures to younger students both in areas that have covered bridges and areas that do not. These educational benefits should include knowing from what era these bridges came, why they were built the way they were, and why they should stand for as long as possible as monuments of past. Not only should the benefits and historical significance of these bridges be discussed in an educational setting, but the legal ramifications of damaging these bridges must also be addressed. Many people may not fully understand that most of these covered bridges are Federally protected, and damaging them can come with large fines and even jail time depending on the severity of the crime committed against them.

Phases of Monitoring or Security System

Four important phases of deploying any monitoring or security system must be thoroughly discussed before any portion of the project begins. For larger bridge owners, such as state DOTs or local governments, it may be possible for all portions of the monitoring or security system to be completed in house but this may not be possible for smaller bridge owners that do not have the capacity. To avoid any problems with the system and ensure that the system is as effective as possible, it is essential that all parties involved are aware of all arrangements and expectations.

Design

The design of the monitoring or security system can be very challenging and time consuming, depending on the level of security desired and the complexity of the system. If an intricate monitoring system is chosen, then software and hardware will be required and this in itself can become a very expensive and challenging problem. For small bridge owners who do not have the capacity of resources for this level of design, then it may be appropriate to outsource the design of the system.

Installation

Installation of any security or monitoring system heavily depends on the complexity and scope of the system. If the system is not very technical, then the installation could be completed by someone outside the security profession. If there are multiple pieces of equipment that must work in unison, then it may be in the best interest of the bridge owner to have a third party install all the equipment. In many cases, the company or individual that designs the system may be the same one that installs the system to guarantee that it is done correctly.

Monitoring

It does not matter how well any system is designed or installed if there is no one to monitor it and respond to any alarms. In most monitoring applications, the system must be monitored by a designated person who is able to react to any type of arson or vandalism. It is important to know what the procedure will be if any alarm is set off at the bridge site. If there are cameras at the bridge site, it may be possible to remotely view the bridge site after any alarm has been set off to see if it is a false-positive alarm.

Maintenance

The implementation of these security and monitoring devices should not be considered the end of any security project. Periodic maintenance of both the equipment and the bridge itself are vital to the survival of the system and the bridge. It may be necessary to renovate the bridge both aesthetically and structurally throughout its life, and both of these issues are discussed briefly in the recommendations portion of this report and also in great detail in *Covered Bridge Manual* (Pierce and others 2005).

Madison County Project

The authors of this report have taken part in a security effort with Madison County in southwest central Iowa to protect five of the six covered bridges in the county. The bridges included within this effort are the Cutler–Donahoe, Hogback, Holliwell, Imes, and Roseman. The Cedar Bridge had a similar security system installed in 2005 by a team consisting of many of the same members. The Cedar Bridge project will be discussed in some detail with a full report on the entire project also available.

History of the Covered Bridges of Madison County

At one point, there were 19 covered bridges in Madison County but because of various reasons, all but five have been destroyed. Although it is unfortunately common for covered bridges to slowly disappear over the years, there has been a push in recent years to protect these historic landmarks. The bridges of Madison County have received heightened awareness because of their increased fame in part from the book, *The Bridges of Madison County*. This book, written in 1992 by Robert James Walker, was quickly turned into a major motion picture by the same name in 1995 starring Clint Eastwood and Meryl Streep (Walker 1992). In 1993, the book received more attention by being named “the book of the year” by Oprah Winfrey, which raised the status of the book and bridges to even a higher level.

Unfortunately, this fame did not protect the six remaining bridges at the time. The Cedar Bridge, the main bridge in *The Bridges of Madison County*, was completely destroyed in 2002 along with a house that was a major landmark in the book. The Hogback Bridge, which also appears in the book, was set on fire in 2003 but the fire was quickly extinguished by local passersby. The Cedar Bridge was completely rebuilt in 2003–2004 and the Hogback Bridge was completely renovated from its damages. These appalling actions caused the County of Madison to team with Iowa State University’s Bridge Engineering Center and the USDA Forest Products Laboratory to install security measures on the Cedar Bridge to dissuade any further damage to the structure.

Because of the effectiveness of this project in 2005, it was decided in 2010 that surveillance equipment of a slightly different variety should be implemented on the other five bridges. The remainder of this case study deals exclusively with the project in 2010–2011 and the five bridges included.

Security Equipment Installed

The same security system was installed on all five bridges included in the 2010–2011 project. The system included a total of two cameras and two detectors: an infrared camera, an optical camera, and two flame detectors per bridge. In addition to the security equipment, numerous communication devices were installed within an enclosure that allowed for storage or information and remote connection to the surveillance equipment via cellular internet connection. The only major difference between systems was at the Hogback Bridge where alternative energy sources were used to power the surveillance system. This alternative energy system is discussed in detail in the Hogback Bridge section of this report.

When compared with the Cedar Bridge Security System installed in 2005, the main difference is that the Cedar Bridge was outfitted with fiber optic temperature sensors. Because of the problems faced by the design team during installation and testing of the fiber optic cables, we decided to not use fiber optic technology on the Cedar Bridge. Fiber optic cables can prove to be an effective means to protect a covered bridge but multiple problems can arise if not installed and operated correctly, as discussed earlier in the equipment portion of this report.

All equipment in the security system for this project was chosen by an information technology professional with experience within the field of security systems. Advanced software settings are not discussed in this report, as they are extensive. Also, information involved in programming all equipment to work properly within the system and all proprietary systems will have differing system set-ups. It is important to carefully read all instruction manuals and ensure that all proper settings are chosen while designing a surveillance system so that the optimum capabilities of the system can be obtained.

The overall system monitoring is completed with a local PC running custom-developed software with communications to all devices being made via a local area network with wireless and wired communication capabilities. Communications outside of the local area network are handled by wireless cellular radio. Three subsystems are used by the monitoring system: a Web camera, an IR camera, and UV/IR flame detectors. From the IR camera technology, the system will monitor output from the camera and detect a predetermined maximum range in which a heat signature will cause the system to activate the alert status. The UV/IR flame detector system uses signal conditioners that convert voltage into readable digital values. When the flame detector detects the presence of a flame, it completes an electoral circuit. The voltage from this circuit is read by the monitoring system and if it falls within the positive voltage range expected, an alert status will be activated.

When an alert status is activated, the monitoring system software activates the optical and infrared cameras to begin collecting buffered imagery from the camera for a specified time frame. For this project, it was decided to record the optical camera for roughly a minute and a half and the infrared camera for roughly 3 minutes. Unfortunately, this recorded video was not able to be sent wirelessly and has to be retrieved manually by the design team. Also, during this time, an email message is generated and sent by the wireless cellular radio network connection to identified recipients indicating an alert status has been reached

Both active and historical images are viewable by anyone who has the system passwords. This was made possible with a cellular modem and a high-gain antenna.

Communication Devices

As mentioned in the previous section, multiple devices used on this project were for communication purposes so personnel could remotely access the surveillance system by an internet connection or to enhance the performance of the surveillance equipment. These items include a wireless router, personnel computer, cellular modem, Web-based remote power switch, signal conditioners, micro servers, power supplies, and power injectors. There are many proprietary systems available for these types of communication devices and the following list of equipment choices are only the selections made the by the BEC design team based on previous projects with similar applications. It is important for any individual design team to choose equipment that can be integrated. The team must feel comfortable using and configuring the equipment.

Wireless Router—An 11G Wireless Nano Router (ESR-1221 EXT) was used to extend a wireless signal to the equipment being used on the bridge. This specific type of router has an upgradeable antenna for an increased wi-fi coverage area.

Personal Computer—The personal computer used on this project monitored the entire system in real time. It was also used to store images that are taken by all cameras during the case of an alarm being set off.

Cellular Radio—In addition to a directional antenna, we used a wireless cellular broadband modem so that all information can be accessed from remote locations.

Web-Based Remote Power Switch—A specific type of remote power switch has a timer function allowing a reboot or shut down times without any actions by in-field personnel. This power switch and its software was used to allow personnel to remotely control four power outlets at one time.

Power Injector for Optical Camera—The power injector used for this project was the POE – IPX-INJ-C. The injector delivers both data and electrical power to ethernet-enabled devices using a single ethernet cable. This eliminates the need to place the ethernet-enabled device, such as the optical camera, near an outlet and gives more freedom to the security system designer on the placement of the device.

Equipment for Flame Detector—The following equipment was used exclusively for the flame detectors.

Signal Conditioners—Two signal conditioners are used for every flame detector at all bridge sites to reduce false positives.

Microserver—A microserver was used on this project to connect the signal conditioners to the wireless connection.

Power Supply—A power supply was used to power both of the flame detectors, and another was used to power the relays in both of the flame detectors.

Cameras and Detectors

As mentioned earlier in this section, each bridge site has a total of two cameras and two detectors including an infrared camera, an optical camera, and two flame detectors. Figure 8 shows the placement of each piece of equipment that is outside of the box. The antenna, IR camera, optical camera, and enclosure are located on the pole roughly 100 to 150 feet away from the bridge, whereas the flame detectors are located within the bridge itself. The exact placement for each bridge site is seen later in the section when each bridge is discussed individually.

Flame Detector—Two flame detectors were installed on each of the five bridges in Madison County on either end of the bridge positioned to cover the largest portion of the interior of the bridge as possible. There were multiple problems when installing these flame detectors including cross bracing and other structural members interfering with the most ideal line of sight. The final placement of the flame detectors for each bridge is shown later.

The flame detector selected for this project senses radiant energy in the ultraviolet (UV), visible, and wide band infrared (IR) spectrums within a 120° of vision. The settings for the flame detectors were set at the 50- to 60-ft range, as most of the bridges are roughly 100 to 120 ft long from opening to opening.

To transfer the signal from the flame detectors to the data collection hardware where its conditioners were located, a trench was dug from the equipment pole to an entry point on the bridge. For most of the bridges, it was easiest to trench to the wooden approach span between the abutment and the bridge opening. From the underside of the approach span, the wire could be easily routed through the bridge to the flame detectors without being seen from the bridge deck. The Cutler–Donahoe Bridge had a newly paved road between the pole and the bridge, so directional boring had to be used in order to not disturb the road. The directional bore

Figure 9. Infrared camera image at Cutler–Donahoe Bridge.

had minimal disturbance except for the entrance and exit points near the pole and the bridge and would be an option for bridge locations where open trenching is unwarranted or undesired.

The flame detectors might not be aesthetically pleasing and would contrast with the rest of the bridge; therefore, we decided to cover the flame detectors with a wooden case that would take on the appearance of a bird house and be relatively unnoticeable when compared with the white metal case. Each camera was also painted brown so as to not draw attention to it when seen through the hole in the box. The flame detector with and without the wooden case can be seen in Figure 8.

Infrared Camera—For this project, only one infrared (IR) camera per bridge was positioned at a certain distance from one bridge entrance, usually within 50 to150 ft to the nearest bridge entrance. The infrared camera used on all five bridges has the ability to produce thermal images in real time at a resolution of 384 by 288 pixels. An enclosure provided by the manufacturer was used to protect the camera from the elements and individuals who would want to damage the camera with projectiles or through other measures. The enclosure for the IR camera had a glass lens that was coated in germanium for optimum thermal transmissivity.

Figures 9 and 10 show images that the IR camera produces. Each image shows the capture date and time as well as the spectrum of temperatures within its field of view, including high and low temperatures. For each of these bridges a person stands within the opening of the bridge. The IR camera points out this area of increased temperature when compared with the surroundings with an arrow and a box with the temperature in it. If these maximum temperatures reach a certain threshhold, then then the IR camera can set off an alarm.

Figure 10. Infrared camera image at Holliwell Bridge.

Figure 11. Optical camera image at Cutler–Donahoe.

Figure 12. Optical camera image at Holliwell.

***Optical Camera*—**Directly next to the infrared camera was an optical camera. The optical camera provided a similar service as the infrared camera except, instead of providing images in the infrared range, they provided images in the visual spectrum. These images were also transmitted in real time over the internet. The camera chosen for this project is designed for outdoor use so no enclosure was required before installation. This camera has the ability to pan and tilt through remote controls that could be controlled remotely.

Figures 11 and 12 show the image that the Panasonic optical camera produces. Compared with the IR camera, this image is fairly basic and is used for simple surveillance purposes. When an alarm is set through the IR camera of flame detector, the optical camera will record video for a specified amount of time and store it for future viewing so personnel can see what caused the alarm to trigger and to have video evidence of any individuals who may be on the bridge during times when the bridge is closed.

Other Equipment—Box

The equipment box storage used at each bridge was the same. A NEMA 4 box, which is the desired classification of box to be used for most applications as stated earlier in this report, which measures 24 in. by 24 in. by 8 in. (H × W × D), was used to store the monitoring equipment at the bridge. A rough sketch (Fig. 13) showed considerable room for expansion but after placing everything inside the box in the field, it proved to have very little extra room with the inclusion of all wires and power supply cords. This can be seen in Figure 14 with the actual in-field layout of the NEMA enclosure.

Because the NEMA enclosure was built to be hung on a flat surface, brackets had to be fabricated to secure the boxes to the monitoring equipment pole (Fig. 15). These brackets were made with basic ¼-in. steel bars that had drilled holes for lag screws and bolts. At the four points where the box was attached to the brackets, an eye bolt was used so aircraft wire could wrap around the pole to provide additional support against the box swaying in the wind.

Challenges with Each Bridge

Cutler–Donahoe

The biggest obstacle with the Cutler–Donahoe Covered Bridge was its location. The Cutler–Donahoe has been moved from its original location to a city park within the downtown area of Winterset, the county seat of Madison County. Because it was located within a city park, it was more difficult to get close to the bridge to complete any necessary construction or attachment of any cameras. A newly constructed road between the ideal pole location and the entrance of the bridge caused multiple problems with trenching for the flame detectors on the bridge as well as getting power from the bridge to the pole.

Initially, we thought that for obvious security reasons the NEMA enclosures should be installed at a height on the poles such that any vandalism or damage would be difficult to accomplish. Therefore, for the first bridge instrumented, the Holliwell Bridge, the enclosure was installed

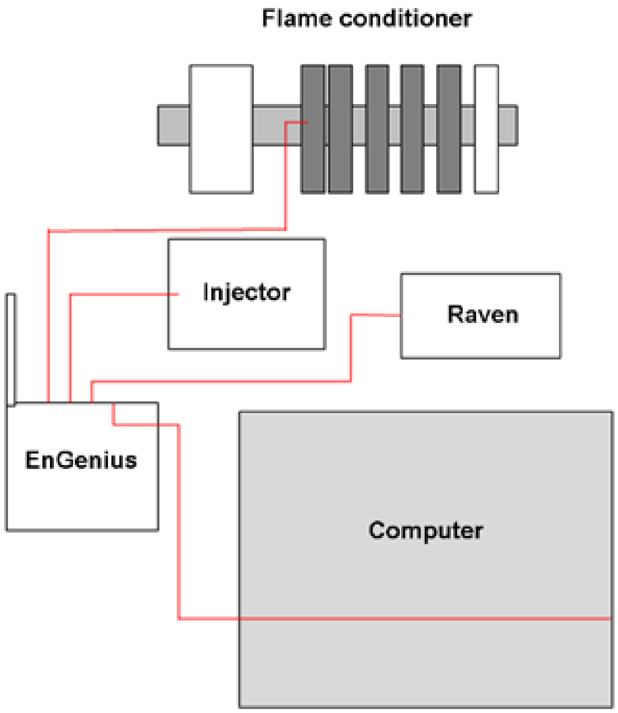

Figure 13. Box layout for NEMA enclosure.

Figure 14. Actual box layout in field.

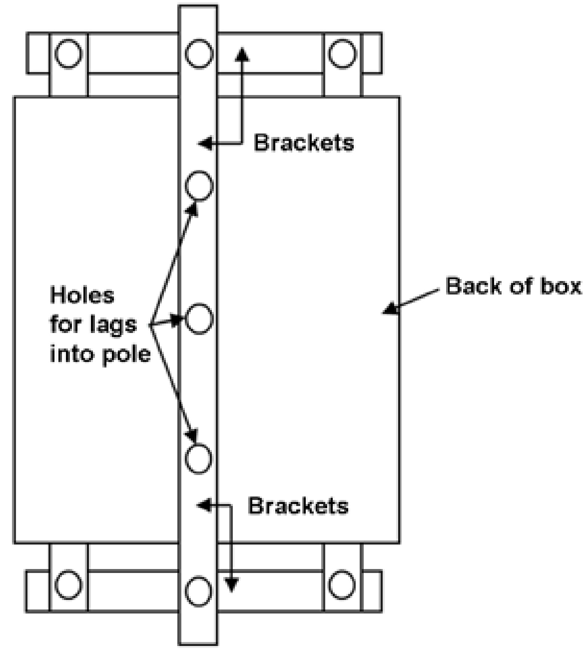

Figure 15. Brackets for box to pole connection.

Figure 16. Cutler–Donahoe pole.

approximately 20 ft from the base of the pole. Shortly thereafter, we determined this was not very user friendly, but also not necessary if other precautions were made. On the subsequently instrumented bridge, the Cutler–Donahoe Bridge, the NEMA enclosure was set roughly 8 ft off the ground as seen in Figure 16. We later determined that this height was still unnecessary and that setting the enclosures at chest height level was sufficient as long as enclosures were properly marked and securely locked. The bridge owner decided on the mounting height of all equipment. If the bridge site has had problems with vandalism, it may be necessary to keep all equipment at a higher level (8 ft or more) to deter trespassers.

The flame detectors for the Cutler–Donahoe Bridge (Fig. 17) were required to be placed in the middle of the openings because of the architecture of the bridge. This caused multiple problems because cross members tended to get in the way of a direct line of site for the detectors. Other bridges allowed side mounting of the flame detectors so that cross members and other structural members did not inhibit

Figure 17. Cutler–Donahoe flame detector that has been activated.

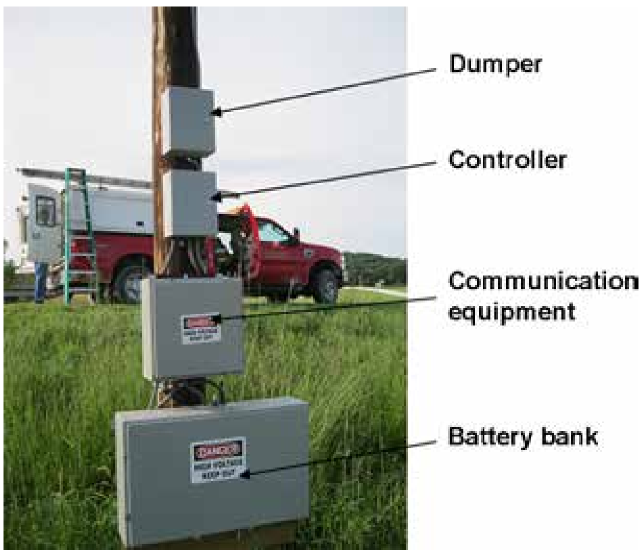

Figure 18. Hogback enclosure set up.

a direct line of a site and were placed optimally. It is essential when installing all equipment, both in the bridge and around the bridge site, to balance the aesthetics of the bridge site with the functionality of the equipment.

Hogback

The Hogback Covered Bridge proved to be the most difficult bridge out of the five instrumented. Because of the isolation of this particular bridge, it cost as much to install line power from the local municipality as it would be to set up a renewable energy system that used solar and wind power in the area. Neither the BEC nor the County of Madison had ever tried to develop such a large, stand-alone alternate energy system prior to this project, so there were initial uncertainties of such an undertaking. After discussing this, we decided to use alternative energy sources with the aid of renewable energy professionals. As seen in Figures 18 and 19, three additional NEMA enclosures for the renewable energy equipment and a 60-ft pole to house the solar panel and wind turbine were required. All of this equipment will be discussed in the following section.

Alternative Energy System—Because a solar panel or wind generator are only rated for ideal conditions, it was important to size all of the equipment for average conditions with a certain safety factor added in case of an extended downtime. After reviewing historical numbers from Madison County, we decided to select a 600-watt wind generator and a 150-watt solar panel with the use of a battery bank that could store reserve power for up to 3 days without stopping the security system (Fig. 20).

Wind Turbine—Instead of using a horizontal axis wind turbine, which is the more common type of wind generator, we decided to use a vertical axis wind turbine that could use less wind speed for more power. There is also a lesser chance that the vertical axis wind turbine will be damaged by sudden wind gusts when compared with its horizontal axis counterpart, which is ideal for the application in Madison County. Another difference between this system and others of similar size is that a common 60-ft telephone pole was used rather than a proprietary pole. Most manufacturers will only warrantee their equipment if it is placed on the pole that they also manufacturer, but some manufacturers will allow their systems to be placed on a professionally installed telephone pole. Significant savings can be seen by not having to purchase a proprietary pole for a wind turbine or solar panel.

Figure 21 shows the construction of the wind turbine within a laboratory setting for testing of power output at different wind speeds. For a frame of reference, the BEC employee in the yellow shirt in Figure 22 is approximately 6 ft tall. Figure 22 shows the complete assembly of the wind turbine in the laboratory setting.

Solar Panel

Battery Pack—Because batteries for solar panels are 12-volt and the power system is 24-volt, we were required to have four batteries in the configuration; two sets of batteries in a series and then the two pairs connected in parallel. Each individual battery had an estimated 225 amp hours and in the configuration of the battery bank was a total of 450 amp hours. Using only 50% of the amp hours available and with a total load of roughly 7 amp hours, the battery bank could provide power to the security system for up to 32 hours without charge from the wind and solar and with the security system running at 100% usage.

Controller—The controller used for this project was an off-grid controller designed specifically for the 600 vertical axis wind turbine (VAWT). The function of the controller is to take the variable 3-phase AC output from the permanent

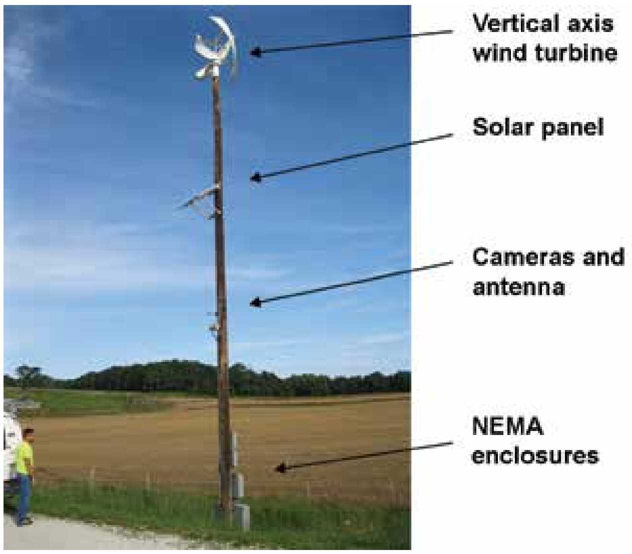

Figure 19. Original Hogback pole.

magnet generator and convert it to a stable 24-volt DC output to charge a battery bank. The controller also manages the turbine so that it performs safely and optimally.

Diversion Load—The diversion load is designed specifically to work with the controller for this particular set up. If too much charge comes from the wind and solar units at any given time, the excess power goes to the diversion load, which dissipates power through the form of heat. This piece of equipment is essential so that the system is not overcharged, potentially destroying the controller or batteries.

Inverter—The inverter used with this renewable energy system was a 24-volt DC-AC pure sine wave. As mentioned earlier in this report, it is essential that a pure sine wave inverter is used when powering scientific equipment. The efficiency of the inverter was 89%; therefore, there was an 11% loss between DC to AC. This loss was accounted for in sizing stages so that the loss did not affect the security system.

Problems with Renewable Energy System

After installing the renewable energy, multiple problems arose with the power output of the system. The system could

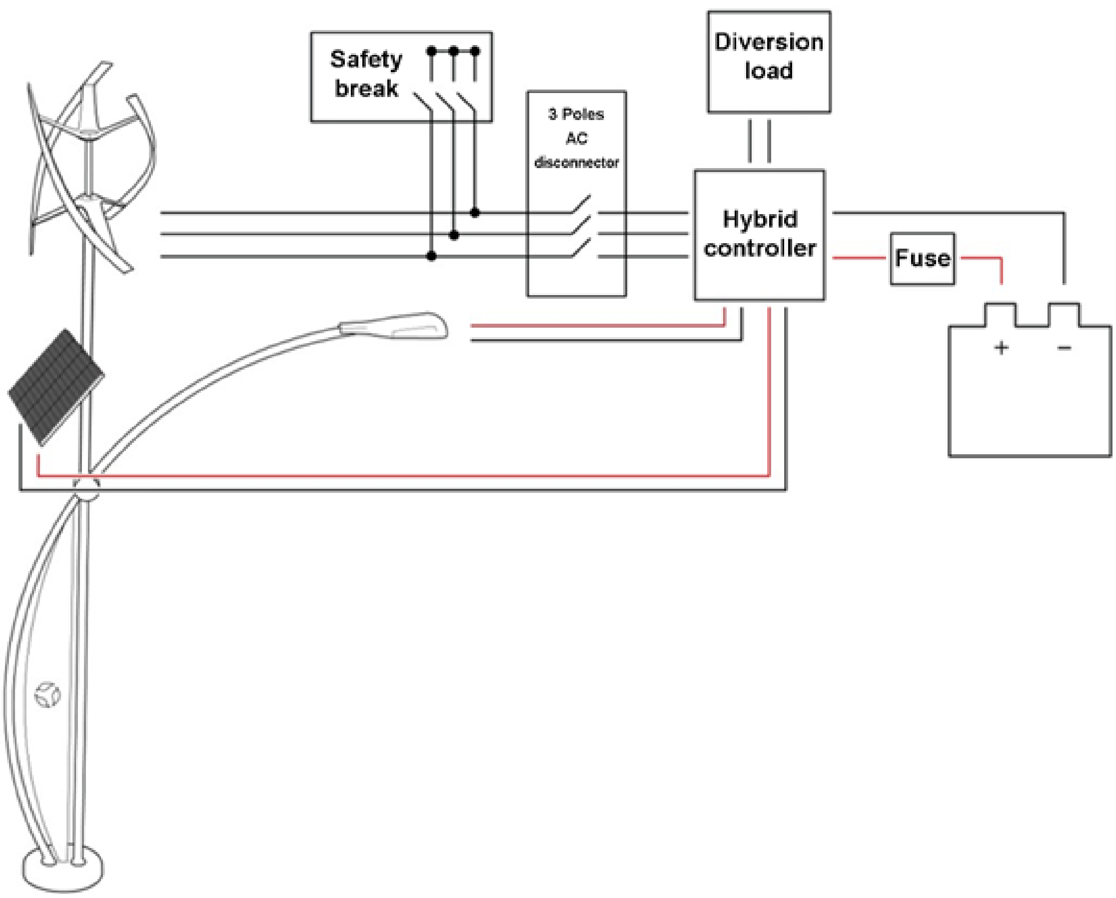

Figure 20. Wiring diagram for an off-grid system with solar and wind power.

Figure 21. Assembly of 600-watt vertical axis wind turbine (VAWT).

Figure 22. Full assembly of 600-watt vertical axis wind turbine (VAWT).

not support the monitoring system that had been installed for more than 4 to 5 days. We decided to slowly start expanding upon the renewable energy system while trying to decrease the power demand from the monitoring system by turning off certain pieces of equipment during different times of the day. The first change to the system was the addition of two 230-watt solar panels as well as a controller that was used solely for these two solar panels. Figure 23 shows the modified renewable energy system with the added solar panels. It can be seen from this photo that the extra solar panels are relatively large when compared with the original solar panel.

Holliwell

Located between Winterset and St. Charles, the Holliwell Bridge was the first bridge instrumented. An instrumentation pole was placed on top of a significant hill with heavy weeds between the bridge and the pole. An above-head power line was the power source for the surveillance system. A pole that was roughly 100 yards away had power already established and we decided that using overhead power lines would be easier and more efficient than trenching between the two poles.

As mentioned earlier, the heights of the NEMA enclosures vary between the different bridges and our initial thinking was to put the boxes high enough that they would be difficult for any vandals to tamper with but still be accessible with a ladder. After installing the box at the Hogback Bridge approximately 20 ft above ground, it was clear that this was not a safe situation for anyone doing maintenance on the system, and it was mostly likely not necessary if the boxes were appropriately labeled and securely locked.

Figure 24 shows one of the optimum positions for the flame detectors to be placed within the bridge. By side mounting the detectors, there was minimum interference with structural members and the best line of site was obtained. Most of the mounting positions at other bridges were somewhere between the side of the bridge and the middle of the opening as with the Cutler–Donahoe and Imes Bridges. As mentioned in the Cutler–Donahoe section of this report earlier, it is essential that the aesthetics of the bridge site and the functionality of the equipment are balanced.

Imes

The Imes Bridge used an existing pole that was moved roughly 20 ft from its original position. The NEMA enclosure was placed at chest height, which proved to be the most efficient height for protection while still allowing easy access into the enclosure. The flame detector was placed much like the Cutler–Donahoe set up in the middle of the bridge opening. Existing power for street lamps was roughly 50 ft away and was hand-trenched to the pole.

Roseman

The Roseman Bridge was one of the easier bridge set-ups because an existing pole in an optimum position that already had power available. This allowed for minimum disturbance with the aesthetic value of the bridge site, as very little had to be changed to install the security system. The flame detector was positioned halfway between the middle of the opening and the side of the bridge. Because of the architecture of the bridge, this proved to be the optimum position

Figure 23. Modified renewable energy system (Compared with original system in Fig. 20).

Figure 24. Holliwell flame detector.

for the flame detectors with direct line of site to the middle of the bridge.

Testing

All five bridge sites were field tested to ensure that all equipment was operating properly. A 1-ft diameter pan was placed on a cart so a fire could be easily moved along the length of the bridge to ensure adequate fire-detection coverage. It should be noted that safety is the most important part of any in field testing that includes an open flame. Buckets of water and fire extinguishers should be close at hand as seen in Figure 25. It is also essential to inform all local

Figure 25. Required material for flame test.

authorities such as police and fire departments that open flame tests will be conducted to ensure any alarms or notifications from passersby can be ignored during a certain time frame.

The test started in the middle of the bridge span directly between the two flame detectors on either end. For some of the detectors to be set off, the fire had to be pushed roughly 10 ft toward the end of the bridge because the center of the bridge had some limitations to direct line of site.

The flame detectors were able to visually show that an alarm had been set off through the use of LED lights that could be seen through the wire mesh in the wooden boxes. A flame detector that is not set off and in working order is monitoring the bridge by blinking the LED lights every 15 seconds. Figure 26 shows a flame detector that was triggered during the fire testing. The red LED lights are constantly on and stay on until the system is reset via either internet connection or by simply cycling the power off and on.

After the flame detectors were found to be in working order, the same fire was started at the opening of the bridge on the side facing the IR and optical camera. Only the IR camera has the capability of setting off an alarm if a fire is present and there is no visual display to show if it is working properly as with the flame detectors. Once the IR camera would capture a temperature that exceeded the threshold temperature preset through the software, an email would be sent and the optical camera would capture a certain length of recorded video.

Example Case Studies

The creators of this manual decided to create multiple, fictitious case studies to show examples of how to implement different monitoring and security systems. These case studies show just one possible solution for each bridge. Numerous types of systems could be installed on each

Figure 26. Flame detector after alarm activation.

Figure 27. Side view of Slaughter House Covered Bridge.

bridge depending on the requirements and financial resources available.

Slaughter House Covered Bridges

Bridge Owner

Town of Northfield

Bridge Location

Northfield, Vermont

Bridge History

The Slaughter House Covered Bridge is a 55-ft long queen-post truss bridge that carries traffic over Dog River by Slaughter House Road. This bridge was built in approximately 1872. This bridge is directly next to a highway and the local community is 1.5 miles away from the nearest fire department that has adequate equipment to put out a moderately sized fire on the bridge.

Figure 27 shows that the mid-span of the bridge is high above the Dog River below and virtually unreachable by local fire departments. This makes it more difficult to protect since a weakened mid-span can lead to total collapse. The lack of easy access deserves special consideration.

Security Option 1

Price: Low

Maintenance Required: Low-Moderate

Protection: Moderate

Equipment: Intumescent Coating, Signage

Because the covered bridge is close to a medium-sized city that has a fire department, the decision can be made to simply protect the bridge and reduce damage. By adding intumescent coating to the smaller bridge elements, such as the siding and roof structure, the bridge owner is drastically reducing the consequences of a fire. For added security, the bridge owner can decide to coat the structural members as well but because these members are harder to initially set, this may not be required. Adding signage to the bridge stating that the trespassers will be prosecuted will further increase the effectiveness of the security with little added cost.

Security Option 2

Price: Moderate

Maintenance Required: Moderate

Protection: Moderate-High

Equipment: Lighting, Flame Detectors

Adding a simple deterrent such as lighting can drastically reduce the chances that a trespasser will try to harm the bridge. This is especially true given the proximity to a major highway and a residential area. Because this option does not provide any protection, it is important that detection capabilities are high. This can be accomplished with the addition of flame detectors at one, or both, ends of the bridge. This will require higher maintenance with the addition of electronic equipment but will increase the security of the bridge.

Security Option 3

Price: High

Maintenance Required: Moderate

Protection: High

Equipment: Lighting, Sprinkler System

The most effective piece of equipment that could be used to protect this covered bridge is a dry pipe sprinkler system. Given the difficult accessibility, a sprinkler system could ultimately help the covered bridge survive if an arsonist was able to start a substantial fire before the fire department is alerted. Because this bridge is close to a residential area, we

Figure 28. Side view of Zacke Cox Covered Bridge.

assume that a local water supply is close. Therefore, a hook up would not be as expensive as a more remote covered bridge. Adding lighting simply increases the protection of the security system by reducing the chance that a fire could be started in the first place.

Zacke Cox Covered Bridge

Bridge Location

Mecca, Indiana

Bridge History

The Zacke Cox Covered Bridge is a 72-ft single-span burr truss bridge built in 1908. It is in an isolated area with scattered farm houses in the vicinity. The nearest volunteer fire department is 4.9 miles away that has the capability of putting out a moderately sized fire.

Figure 28 shows a side view of the Zacke Cox Covered Bridge when the stream underneath it is completely dry. The stream is rarely completely full and can be easily walked across, allowing firefighters to get below the river and fight the fire from underneath the bridge if necessary.

Security Option 1

Price: Low

Maintenance Required: Moderate

Protection: Low-Moderate

Equipment: Intumescent Coating, Lighting

The simple addition of intumescent coating will reduce the chance that a major fire can occur at this bridge. The addition of intumescent coating on covered bridges is an attractive option for a bridge owner that does not want an expensive system or multiple pieces of electronic equipment. Maintenance will be required with this system but it will not usually require a completely new coat of intumescent coating for several years.

Security Option 2

Price: Moderate

Maintenance Required: Moderate

Protection: Moderate-High

Equipment: Intumescent Coating, Flame Detector

The addition of a flame detector will alert the fire department if a fire has been started on the bridge. This is important, as the fire department will have a 5-mile journey to get to the fire. Maintenance will be increased with the addition of a flame detector. However, this equipment will help to ensure that the fire department has as much notice as possible.

Security Option 3

Price: High

Maintenance Required: High

Protection: High

Equipment: Intumescent Coating, Flame Detector, IR Camera

The addition of an IR camera increases the level of protection from a fire by adding a level of security on the outside of the bridge. It can also be used to monitor individuals approaching the bridge at certain periods of the day. Given the remote location of the bridge, it is essential that all fires are detected as soon as possible. With the increase of electronic equipment, this will obviously increase the amount of maintenance required at the bridge site.

Real Case Studies

A national search was conducted to find different projects throughout the United States that included adding monitoring devices and different security equipment on covered bridge sites. Very few covered bridge owners were installing any monitoring devices, and a couple were adding other security systems such as lighting or fences. The majority of security installations dealt with structural strengthening and renovations to the bridges such as applying fire resistant materials to various components. These types of projects were not included in to the case studies as they did not add any sort of monitoring system on to the bridges.

Union County Covered Bridges

Bridge Names

Bigelow Bridge
Pottersburg Bridge
Culberson Bridge

Bridge Owner

Union County Commissioners

Bridge Location

Union County, Ohio

Initial Price of Security System

$215,619.00 (for all three bridges)

Bridge History

These bridges in Union County, Ohio, have had arson and vandalism problems but nothing major to this point. There have been fire problems from people starting camp fires on the river banks under the bridges but nothing that appeared to be intentionally set.

Security System Overview

The security systems on these bridges use a linear heat detection cable located along the edges of the truss space as well as one cable down the center of the ceiling space. A Fenwall system with a Honeywell remote dialer was used for the linear heat detection system. Two cables also run the width of the bridge above the abutment areas of each bridge (Cable placement shown in above image). Once the detection cable is set off by a certain temperature, an audible and visual alarm is set off and an alarm is sent to the fire department.

All four bridges were also equipped with Tokistar LED lights that were modified to withstand vibration from traffic on the bridges. The LED lights were located under the roof to aesthetically wash down the walls of each bridge. The LED lighting is used to make the structures more visible with the hope of reducing the chances of someone damaging the bridge during nighttime.

Knecht's Covered Bridge

Bridge Name

Knecht's Covered Bridge

Bridge Owner

Bucks County, Pennsylvania

Bridge Location

Springtown, Pennsylvania

Initial Price of Security System

$35,000.00

Source of Funding

Privately funded

Year Installed

2011

Bridge History

Bucks County has lost three covered bridges from arson since 1985 and almost lost another one when Knecht's Covered Bridge was set on fire twice over a 3-year period with the last attack in 2007. Hay bales were placed on the bridge with a trail of accelerant and lit by a match. Fortunately for Bucks County, the hay was damp, so it smoldered instead of becoming set ablaze.

Security System Overview

The security system for the Knecht's Covered Bridge included an alarm system with strobes and horns. These alarms are connected to a linear heat detection system that is controlled by a control panel enclosed in a NEMA 4 enclosure. There is also a dry standpipe sprinkler system across the length of the bridge to protect in case of any fire reaching a certain temperature threshold.

Pomeroy–Academia Covered Bridge

Bridge Name

Pomeroy–Academia Covered Bridge

Bridge Owner

Juanita County Historical Society

Bridge Location

Port Royal, Pennsylvania

Initial Price of Security System

$16,600.00

Bridge History

It is unknown exactly when the Academia Covered Bridge was originally built, but this bridge was destroyed by ice floating down the river in 1901 and was promptly replaced with a new bridge that still stands today. In 1962, the Pomeroy–Academia Covered Bridge was scheduled to be completely destroyed and replaced with a new concrete bridge to span the river. The Juanita County Historical Society took prompt action and acquired the bridge and allowed it to stand.

In June 2009, weeks after $1.4 million was allocated for restoration of the bridge, suspected locals attempted arson. The individuals lit articles of clothing on fire and damaged some of the bridge deck. A few days later, the same individuals, as thought by the local police, returned to extensively spray paint graffiti throughout the bridge.

Security System Overview

An eight-camera security system was placed throughout the bridge site as well as within the bridge itself for a total of $14,000 and all the graffiti was removed and a coating of fire retardant was applied to the burned area for a total of $2,600.

Cedar Covered Bridge

Bridge Name

Cedar Bridge

Bridge Owner

Madison County, Iowa

Bridge Location

Madison County, Iowa

Source of Funding

Federal

Bridge History

The Cedar Bridge was a major bridge in the 1992 book *The Bridges of Madison County*. In 2002, the Cedar Bridge was completely destroyed by arson. The town decided to rebuild the bridge with the same construction methods and materials as the original bridge and it was completed in 2004.

Security System Overview

An extensive security system was designed and installed on the Cedar Bridge with a grant from the USDA Forest Products Laboratory. This integrated system included an infrared camera, fiber optic temperature sensors, and two flame detectors at either end of the bridge.

Security System Technical Data

Major Equipment

One thermal imaging camera.

Two electro-optical digital fire detectors were used with the specification of the detection of a 1 ft^2 fire at 15 ft within 5 s. Twelve fiber optic sensors.

One optical sensing interrogator.

Additional Information

A detailed report for this project can be found in *Remote Monitoring of Historic Covered Bridges* (Phares and others 2010).

Illinois Covered Bridges

Bridge Name

Red Covered Bridge

Thompson Mill Covered Bridge

Bridge Owner

Illinois Department of Transportation

Bridge Location

Bureau County (Red Covered Bridge)

Shelby County (Thompson Mill Covered Bridge)

Initial Price of Security System

$74,450.00 (Red Covered Bridge)

$71,090.92 (Thompson Mill Covered Bridge)

Year Installed

2005 (Both bridges)

Bridge History

Before the improved security systems were installed on this bridge, some basic light fixtures were located in the interior and openings of the bridges. These basic fixtures included three wall-mounted luminaires located inside the bridges and one pole-mounted luminaire on the North approach.

Security System Overview

Two light fixtures were installed on the bridge during the security system improvement. These light fixtures will be controlled by photocells that turn the lights on when the ambient light levels fall below a certain threshold. A single architectural floodlight on the south ensures that both approaches are lit. A triple architectural floodlight is directed at the existing parking lot. After the renovation to the lighting system, the interior of the bridge, both approaches, and the parking lot are completely lit during all hours of the day.

Along with the increased lighting are five cameras placed throughout the bridge site. A camera in the entrance on both the north and south side of bridge faces toward the center so the entire interior of the bridge is under surveillance. A camera on the ends of both the north and south approaches faces toward the entrances of the bridge. A camera is also mounted with the triple architectural floodlight facing towards the mechanical building.

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