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# BRIDGES & WILDFIRE EVENTS

## IDENTIFYING INFORMATION GAPS IN BRIDGE PROTECTION IN THE CONTEXT OF RESISTANCE TO WILDLAND FIRE EVENTS

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This report is not restricted.

## ABSTRACT:

The Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) has asked FPInnovations to investigate current information and knowledge for bridge fire impact mitigation opportunities and strategies.

The extent of the investigation includes reaching out to domestic and international contacts to find directly applicable information and literature on strategies to mitigate fire impacts to bridge structures. This will include review of academic journals and reports, products and methods, to find relevant information and identify knowledge gaps related to bridge fire protection.

The knowledge gaps will be used to shape potential future projects on this subject.

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# INTRODUCTION

Consecutive record fire seasons in 2017 and 2018 in British Columbia (BC) have placed increased attention on the effects of wildfires. These wildfires affect resource roads and structures that provide critical access to rural residents, communities, and natural resource management entities.

Among the different elements of resource roads, bridges are a critical component, and are both expensive and challenging to protect or re-build. Improving the resilience of bridges to wildfires is therefore an essential part of road protection activities. To facilitate the mitigation of bridges from wildfire events, we must first research the existing literature to have a thorough understanding of how damage to bridges have occurred from wildfires, if any pro-active protection measures and strategies have been employed or studied, and if so, review their efficacy.

The Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) has asked FPInnovations to carry out this review pertaining to fire events and bridges. The objectives of this review are as follows:

1. Review and summarize existing industrial reports, academic literature, and/or government reports pertaining to wildfire events and bridges. This includes making international contacts to determine if work has or is taking place internationally on this subject.
2. Draw on BC Wildfire Service (BCWS) and their knowledge and connections for potential methods and products intended to mitigate wildfire impacts to structures and bridges.
3. Identify proven protection techniques and strategies that may exist that could be effective and potentially employed.
4. Identify any knowledge gaps from the existing literature. Use the found knowledge gaps to recognize potential projects or directed research that can be effectively undertaken to fill these gaps.
5. Comment on the value, applicability and potential effectiveness that these potential projects can bring.

The value obtained from this review will aid in understanding the current status of knowledge on bridge interaction with wildfires, and mitigative opportunities. Documenting information gaps will assist in identifying what opportunities for bridge protection exist to be potentially pursued to improve the resilience of bridges in wildfire events.

# REVIEW OF EXISTING LITERATURE

The procedure stated below was followed to conduct a review of existing literature that specifically pertains to bridges and wildfire events:

1. Brief search to find events wherein bridges have been impacted by wildfires, to showcase instances of such events occurring.
2. Make domestic and international connections to see if any past work has been already done on this topic.
3. Internal Search - Search and review FPInnovations Wildfire Operations Group's past documents to find information on projects related to bridge protection.
4. External Search - Search, review, and summarize any existing literature outside of the FPInnovations domain. This includes journal papers, conference papers, other academic literature, government reports,

industry reports, etc. for information on wildfire events and bridges. Connect with BC Wildfire Service to determine if they have suggestions to pursue.

The intention of breaking down the literature review in this format as opposed to a conventional literature review is to identify and properly categorize the sources of information. With this format, it is easier to pursue follow up enquires for further information, if required.

## Instances of Bridges Being Impacted by Wildfires

The following is a list of few known instances wherein wildfires have adversely impacted bridges. The purpose of this list is to showcase the susceptibility of bridges to wildfires, and to develop the basis for proactive measures to protect them.

1. **Okanagan Mountain Park (BC) –** This lightning-caused fire in 2003 claimed at least two historic railway trestle bridges and damaged two others. The affected bridges cut off key routes for firefighters and threatened the historic Kettle Valley railway line.
2. **Steen River (Alberta) –** This recent 2019 fire caused a CN railway bridge that connects Hay River (N.W.T.) to the south to burn down. The trestle bridge warped due to the heat from the fire and had to be rebuild. At the time, access to Hay River via High Level by highway was also cut off due to wildfires in the area – thus highlighting the importance of this bridge as a route for goods transportation. At the time of writing this report, the cause of this fire is to be determined.
3. **Ladner Creek Trestle Bridge (BC) –** In 2018, a discarded cigarette butt caused ignition of the trees around Ladner Creek Bridge. While the size of the fire might be minimal in terms of area, the bridge continued to smolder and burn for multiple days, proving to be challenging to suppress.
4. **Butte County Bridge (California) –** Also known as the Honey Run Covered Bridge that connected Chico and Paradise, this bridge was destroyed in 2018 during the Camp Fire that was started by electrical transmission lines.

***Note:*** *There are several other instances of wildfires impacting bridges that are not listed here. This list is primarily used to highlight instances of such events (wildfires impacting bridges) occurring.*

## Extent of Search

To make sure similar work had not been done before, several agencies and other entities were contacted to inquire about their knowledge of any documentation related to bridges and wildfire events. Contacts were asked to inquire among their fellow colleagues for information as well as query any internal libraries/databases they might have access to. The following entities were contacted in this effort:

1. FPInnovations
    a. Wildfire Operations
    b. Transportation
    c. Forest Engineering
    d. Roads & Infrastructure
2. University of Alberta
    a. Department of Renewable Resources (Wildfire Analytics)

   b. Department of Mechanical Engineering (Thermal Spray)
   c. Department of Human Ecology (PCERF)
3. Myac Consulting Inc.
4. Wild Rose Fire Behaviour
5. Ontario Ministry of Natural Resources
6. Saskatchewan Ministry of Environment
7. NWT Environment and Natural Resources
8. British Columbia Wildfire Service
9. Alberta Agriculture and Forestry
10. Canadian Forest Service
11. Scion (New Zealand)
12. CSIRO (Australia)
13. National Institute of Standards and Technology (USA)
14. U.S. Forest Service (USA)

***Note:*** *The names of contacts have been masked in this list since permission to use the contacts' names was not obtained. In addition, their responses are not the official position of their employers on this matter.*

Responses from all but two entities were obtained. The common message from all entities was that they are unaware of any documentation related to bridges and wildfire events. Wildfire agencies generally do not go to the extent of documenting bridge damage during a wildfire event. It is outside the scope of their work. Moreover, bridges are often owned by private rail companies, thereby providing less incentive for agencies to document any impact wildfires have on bridges.

# Internal Review of Past Research

FPInnovations' Wildfire Operations group has done several projects over the years related to structure protection. Of direct applicability to bridges and wildfire events is the CN Project wherein components of the project focused on bridge protection. Prior to reviewing the contents of this research project, it is worth noting that the CN Project was a contract project between FPInnovations and CN, with majority of the documentation proprietary in nature. The findings from the project were submitted to CN in confidence. Therefore, the following summarized information are the only details that are retrievable and from the public domain.

## CN Contract Project

To gather relevant information from this CN Project, the Wildfire Operations Group's Fall and Spring Advisory Meeting minutes was reviewed from 2005 to 2015. The project involved looking at different aspects of bridge protection:

### Phase 1: Tested Radiant Stand-off in Grass Fires

Bridge timber and power poles were tested in grass fires on Vanderwell Contractors' land near Slave Lake. The test involved the use of intumescent paint on wood where the paint would expand on exposure to heat and provide insulation for the wood. The setup involved a 1-3 meter gravel pad around the timber, with a grass fire running past the test specimens. Three burns were completed with 11 samples in total – 4 railroad timber and 7 power poles. Of the samples, 6 were treated with the paint while 5 were left untreated. The intumescent paint was painted up to one week prior to the burn.

No sustained combustion was found on the treated wood, whereas all the untreated wood ignited during the passage of the fire. The intumescent paint was successful at preventing combustion in this specific radiant heat test. Spotting of embers into the cross-arms was brought up as a concern.

### Phase 2: Larger Scale Tests with Cross Beams

This study investigated the effectiveness of fire protective coatings on creosote timbers. The test looked at the ignition and rate of spread on simulated bridge structures. Both treated and untreated cross beams were used in the study, with ignition occurring from a point source. It was found that the treated timber did not prevent ignition and spread.



**Figures 1.** **Figure 2.**
Point source ignition cross beam tests showing "exponential rate of spread"
(Bridge Timber Protection, Thomasson 2013).

### Phase 3: Using Less Flammable Species Around Bridges

No documented work was done on this topic.

### Phase 4: Use of Detection Cameras

A test procedure was developed at the Moose Lake Bridge near Bonnyville, Alberta to validate product capabilities of short-range fire detection systems. The intent of the test was to determine the maximum distance at which systems can detect a small heat source (<0.01 $m^2$). Initial tests with Insight Robotics proved inconclusive. Continuation of the test was later terminated citing infeasibility due to limited range and detection time.

# External Search

## Method

To find external sources of literature, three different search engines were used:

1. ScienceDirect – Peer-reviewed journals, articles, book chapters and open access content
2. Google Scholar – Academic journals, books, conference papers, theses, dissertations, technical reports, etc.
3. Fire Research Institute – Library of books, journals, training manuals, news reports on wildland fires.

Relevant documents related to bridges and wildfire events that were found from the search are summarized below.

## Summaries

### Ignition of Imber Bridges in Bushfires (Dowling, 1993)

***Note:*** *It is recommended that this paper is read in detail. This summary does not capture all of the valuable information within this paper. Given the limited documentation available on this topic, this paper holds importance.*

This study focused on timber or part-timber bridges that were damaged (whole or partial) during the Australian 'Ash Wednesday' fires of 1983 and bushfires during the 1984-85 summer season. The objective was to investigate how timber bridges ignite and burn in fires as well as consider potential remedies to mitigate this risk. The study involved gathering information from witnesses, as well as lab and field experiments.

A total of 17 bridges were reviewed. It was found that that embers were the primary cause of ignition in timber bridges, with common vulnerable points being on the deck, either between deck planks, or against gravel beams. Aged timber was also found to influence the rate of smouldering on bridges. Heat from the fires was found to be sufficient to warp steel beams on the bridges. A review of a subset of bridges being reviewed suggested that "ignition of the deck appeared to be limited in areas where a good bituminous seal existed, or where a build-up of clay and gravel against the gravel beam occurred."

*Laboratory experiments:* These experiments involved ignition of mock-up bridges, presented by a deck plank, gravel beam and cross beam. The effect of surface paint: an exterior acrylic paint and an intumescent paint, was studied. Deck planks with a paint system was found to prevent ignition; however, no differences were found between the two paint systems. This suggests that the paint's surface layer was able to alter ignition characteristics.

*Field experiments:* Tests were performed on a redundant timber bridge under less than ideal burn conditions. The results from the experiments were therefore considered conservative. The experiments were of two types: ember ignition of the deck, and flame ignition of the vertical members under the bridge. Two treatments were of interest: an aqueous solution of diammonium phosphate (DAP) and a waterborne intumescent paint. It was concluded that application of treatments may have an advantage only if applied wholly (i.e. to the entire surface area of the bridge). The intumescent paint prevented ignition more often than the DAP solution.

### Evaluating Fire-damaged Components of Historic Covered Bridges (Kukay et al., 2016)

This study focuses exclusively on historic covered bridges in the United States. Ignition sources beyond wildfires such as arson have been considered in this report. While the interest is primarily on evaluating the damage that has already been incurred, valuable information about existing and exploratory approaches to mitigate bridge fires can be found in this report.

The report discusses thermal degradation, ignition and charring of wood, stating that temperatures in excess of approximately 300°C represent the threshold beyond which significant degradation of wood starts to occur. The report goes on to discuss the impact of high temperatures on the mechanical properties of wood and the fire resistance ratings of exposed wood elements. This information can be used as thresholds during any empirical testing of bridges against heat transfer from fires.

Preservative-treated wood is also discussed, with the author emphasizing a 'special concern' for bridges that use creosote treated wood, citing the flammable nature of the product. Chromated copper arsenate (CCA), another preservative treated for wood, is stated to have the potential for after-glow, resulting in the slow consumption of the wood after receiving only minimal surface charring. Boron-based preservatives are suggested as a potential option for above-ground applications where leaching is not an issue.

An important 'design for fire protection and control' measure that the author suggests is the removal of ignitable materials around a bridge. This continuous maintenance measure can help minimize the ease of ignition. The author however states that firebrands from wildfires are still the primary method for ignition of bridges and therefore protection from embers must be prioritized.

Also discussed is the careful material selection when replacing parts of bridges, especially given that chemical treatments are now available that can reduce the rate of flame spread after ignition. Pressure-impregnated fire-retardant-treated wood can delay ignition, slow the spread of flames, and reduce the heat release rate. However, caution must be exerted since these products can adversely affect the strength properties of wood.

Fire protective coatings (both intumescent and non-intumescent) are also suggested wherein a thermal barrier is formed when the coatings are exposed to heat that will protect the degradation of wood for a certain time period.

Installation of gypsum boards in smaller compartments that can trap embers is also recommend. Finally, the report also discusses security and fire detection monitoring systems to reduce response times.

### Laboratory Investigation of Fire Protection Coatings for Creosote-treated Timber Railroad Bridges (Clausen et al., 2014)

This study focuses on evaluating six barrier treatments for their ability to protect creosote-treated timbers from fires. The motivation behind this study was to reduce ignition caused by hot metal objects such as brake shoes from trains. While not directly related to mitigation against wildfires, it is reasonable to extrapolate the behaviour of hot metal particles as embers from a forest fire. In both cases, it is point sources of ignition making direct contact with the bridge that causes damage. The authors of this report use this extrapolation themselves in the report's introduction.

Creosote treated crossties, both new and weathered, were used in this study. The different barrier treatments were applied on the surface, cured for 4 weeks at 70°C and 50% relative humidity. The barrier treatments selected were:

1. Concrete-like mixture of sand, ash, magnesium oxide and potassium phosphate
2. Latex paint augmented with potassium aluminum sulfate
3. Latex-based intumescent fire retardant (FR) coating, designated NT1
4. Latex-based intumescent FR coating, designated NT2
5. Water based, thin film intumescent FR
6. Clear penetrating intumescent FR

The products were tested for leaching, weathering, bond durability, etc. For fire performance evaluation, four tests were run: mass loss calorimeter, FPL Schlyter test, flammability of large timbers, and hot metal test. The 'flammability of large timbers' test was the closest to replicating real-world conditions with temperature, wind speed, and fanning all accounted for. The 'hot metal test' was a newly developed test exclusively for determining the behaviour of wood when exposed to a hot metal that served as the ignition source.

The conclusion drawn from the initial screening for fire performance using the mass loss calorimeter and the FPL Schlyster test was that not all the products were fire resistant. The two other fire performance tests in combination with weathering and bond durability tests led the authors to conclude that only one product (NT1) provided adequate fire protection.

### Detailed Analysis of the Causes of Bridge Fires and Their Associated Damages (Peris-Sayol et al., 2017)

This study focuses on 154 bridge fires, establishing the main factors involved in bridge fire damage. While most of the bridge fires reviewed in this study were related to hydrocarbon fires in urban and semi-urban environments, a small subset included bridges that were ignited by forest fires or arson. Hydrocarbon fires still provide useful information in understanding fire protection measures.

The four categories of bridges reviewed are reinforced or prestressed concrete, steel, composite steel-concrete, and wooden structures. A combination of pre-defined damage levels (1-6) and a statistical analysis of the variables involved in bridge fires (e.g. bridge structural system or deck materials) suggested that wooden bridges have more intense fire behaviour than bridges made of other materials. Details from the statistical analysis showed that 79% of wooden bridges collapsed in the event of a fire with incurred damage levels substantially higher than bridges made of other materials. The study points out that no cases of bridge collapse in concrete bridges was found; however, nine cases of composite steel-concrete bridges collapsed in fire events.

The study also found that higher damage levels occur via direct heat transfer to the bridge structure; for example, instances where materials are stored under the bridge. Extrapolating from an urban to a wildland setting, this suggests that proper maintenance and clearance of vegetative fuels is of importance.

### Other Partially Relevant Documents

The following are other documents that contain useful technical information that discuss in detail the performance characteristics of different bridge materials when exposed to heat. This information can be used to design experiments in the event of empirical bridge fire tests.

1. Fire hazard in bridges: Review, assessment and repair strategies (Garlock et al., 2012)
2. Post fire bridge assessment procedures (BC Government – FLNRORD, 2018)
3. Strategies for enhancing fire performance of steel bridges (Kodur et al., 2017)

4. Valencia bridge fire tests (Alos-Moya et al., 2017)

Only 'Post fire bridge assessment procedures' has direct relation to wildfire events. The remaining documents discuss information from the perspective of hydrocarbon fires.

# DISCUSSION

## Knowledge Gaps

The following are general observations and knowledge gaps identified during this literature search:

1. There are very few documented research reports related to bridges and wildfire events.
    a. Any documentation on bridges damaged by wildfire events often discuss the event as a whole and do not dissect the event from a technical or scientific standpoint (Example: news coverage, rail company updates, etc.)
    b. Most documentation on bridge fires are related to events in the urban or semi-urban environment where the source of ignition is hydrocarbon fires.
    c. Government agencies dealing with wildfire operations find that bridge protection activities are often outside the scope of their work.
    d. Bridges owned by private companies have no obligation to publish any documentation on bridges consumed by wildfires.
2. Multiple journal articles reviewed for this study emphasized the lack of standards and codes (both American and European) directly related to the design of bridges with fire performance taken into consideration.
3. The limited information found on intumescent paints and coatings are not very useful:
    a. Different studies conducted different tests with mixed results. The aggregated studies in this literature review suggest that the performance of intumescent paints are inconclusive and will depend on the mode and intensity of heat transfer.
    b. Only one study stated details about the type (product) of intumescent paint used. Detailed product information should be required for any operational application or testing to take place.
4. Limited empirical tests have been done to evaluate the performance of bridges in wildfire events. With the numerous variables (type of bridge, construction material, forms of heat transfer, sealants, fire resistant coatings, etc.) involved in bridge protection against wildfires, more tests will always be more beneficial.
5. The value of empirical tests is further emphasized when considering the numerous studies that have modelled bridge fires. While these models are mostly for urban bridge fires, valuable information can be obtained from them about bridge performance. These models need to be validated with empirical tests.
6. The use of fuel treatments and insulation boards as methods of mitigating risk has not been fully explored.

## Potential Actions

Possible measures that can be taken to either test for efficacy or for implementation can be categorized into proactive and continuous measures.

## Proactive Measures

1. Intumescent paints and meshes have had mixed results in previous tests. Their performance is dependent on the mode and intensity of heat transfer. Further testing is required to properly define which products are being tested and record their performance against conductive and radiative heat transfer at varying intensities. Other application characteristics such as bond durability, weathering, etc. will also have to be considered. This material performance testing can be extended to wood preservatives, wood-fire retardants and fire protection coatings.
2. Water management techniques such as remote start pump (Thomasson, 2008) and sprinkler system can be used to pre-wet structures. Dowling et al. (1993) reported that maintenance crews that pre-wet bridges prior to the arrival of the fire front still found points of ignition after the fire had passed. Details about the time frame between the wetting and the fire as well as the efficiency of the wetting are lacking in the report. It is however known from past research (Walkinshaw, 2009) that sprinklers can protect structures from crown fires. There is value in exploring if water systems can efficiently increase the mortality of embers landing on bridges that could cause ignition.
3. Fire protective shield or blankets are another way to protect against embers. The performance of these products against embers are likely good, considering these products have been tested against welding sparks and hot metals. However, their performance against sustained heat transfer is unclear. In addition, their durability in varying environmental conditions such as rain is also unclear. Tests to evaluate such products will help answer these questions. The shields or blankets, if of sound efficacy, can be used in key structural areas that are likely to collect embers.

***Note:*** *The use of wildfire suppression chemicals such as foam, water enhancers (gels), or retardants have been considered but are not recommended for use. These products are generally not permitted to be applied within 100 metres of waterways. In addition, these chemicals break down when exposed to UV light and therefore will not work as a long-term solution. These chemicals are also corrosive at certain concentrations.*

## Continuous Measures

Continuous measures include (vegetative) fuels treatment and (vegetative) fuels management measures in areas surrounding bridges. This could involve:

1. Decreasing fuel load around bridges via thinning/pruning of fuels or increasing spatial separation between fuels. Stand-thinning and stand-cleaning have all shown to reduce fire intensity (Mooney, 2013; Moghaddas et al., 2008).
2. Species conversion to a less flammable species is another option to reduce the fire hazard around structures (Baxter & Woosaree, 2013).
3. Modifying fuel loads around bridges with techniques such as mulching have also proven to reduce fire hazard (Glitzenstein et al., 2006). Mulching of fuel also converts vertical fuels into horizontal fuels that make suppression activities easier to manage.
4. Complete fuel removal such as grass around bridges will also help reduce hazard. This can be done at different scales, ranging from simple vegetation removal to the creation of fireguards using handtools, heavy equipment, prescribed burns, or a combination of different methods.

# CONCLUSION

Increases in the frequency and severity of wildfires pose a big risk for bridges. To better protect bridges, a literature review was conducted to understand existing research in bridge protection efforts. An internal and external search for documentation was conducted, with several domestic and international agencies contacted to source information.

The search suggested that there is very limited research that has been done on bridge protection against wildfire events. With the limited literature found, several knowledge gaps were identified. The key gaps recognized were the lack of standards and codes related to fire protection of bridges and the limited number of empirical tests that have been done to fully understand the performance of bridges against different heat transfer modes.

Moving forward, it was proposed that efforts should be concentrated on more empirical tests on bridge protection products such as intumescent paints and meshes, fire protective blankets, and insulation boards. In addition, vegetative fuels and water management options should be considered as a hazard reduction practice around bridges.

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