Heritage Aspects of Bridge Engineering

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Abstract

Century-old bridges may seem functionally obsolete, but their historical relevance should not be lost on the professionals managing these wonderful structures. Two components of heritage are of interest to the London, Ontario engineers who maintain these structures: their purpose, place in time and local relevance; and, their technical engineering heritage reflected by patents and design methods of the day.

London's early steel and wrought iron truss bridges are being considered for preservation, enhancement and a continued life. Their future is being assessed with a heritage component built into standard bridge management methods: infrastructure lifecycle planning; expansion and capacity growth planning; environmental assessment studies; and, risk assessment.

Bridge managers and engineers have approached the remnants of London's Victorian era of bridge construction in a pragmatic way, taking advantage of heritage documentation and local community input to provide context for design objectives. Consequently, unique features have emerged that transform the timeworn into the revitalized. The project approaches, design features and outcomes are quite varied in four recent London examples.

London's achievements on older bridges have been recognized with an award from the Architectural Conservancy (London Regional Branch) and the Heritage London Foundation for its "outstanding contribution made to the preservation of London's built heritage".

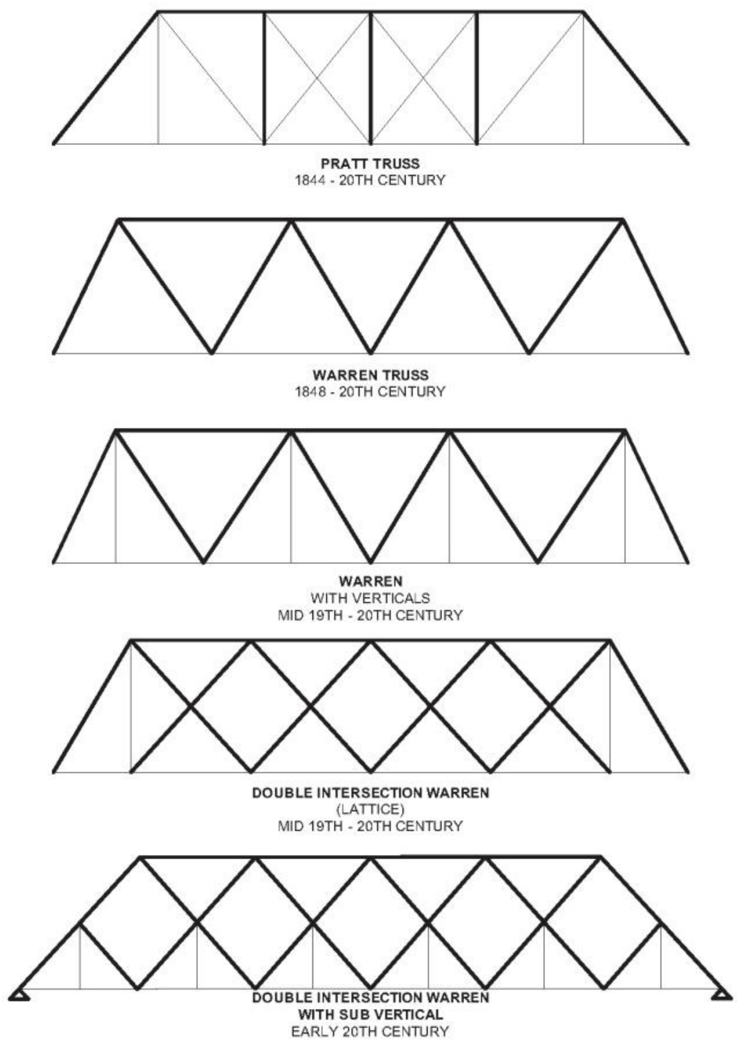
Introduction

Nestled between branches of the Thames River, early London and surrounding townships required river crossings to connect the farming community to the local market and mills. The advent of rail service brought more transportation structures over the Thames and road bridges over rail tracks.

Figure 1 – Blackfriars Bridge (1875)

Early bridge builders in the area constructed wood Queen and King Post trusses that, due to weak material properties, had limited span lengths. The resulting multi-span bridges required intermediate piers in the river. The annual spring freshet, often in February, washed these out, or they succumbed to rot after a limited lifespan. At two of the bridge sites presented in this paper, three or more wood structures were constructed in succession before metal structures that could span the full river width became available. London's first metal bridge, built of wrought iron in 1875 (Figure 1), is still in service; a testament to the durability of the material and design of the day.

Figure 2 -- Truss Styles (1)



Steel truss bridges were the norm in the late 19th and early 20th centuries. In this period, vehicular traffic consisted of streetcars and horse-drawn wagons although the designers of the day correctly recognized that pedestrian loadings were more critical (8). Local bridge builders essentially had to sub-contract out-of-town bridge manufacturers whose product was often selected from a catalogue. A truss bridge in the London area typically had multiple contractors: the bridge fabricator erected his product after a local contractor built the abutments and later, the deck. Although initially more expensive than a timber bridge, the long-span capabilities of metal trusses, by eliminating piers in the river, ensured continued service for a lower lifecycle cost.

Pratt and Warren trusses were the norm. The span dictated which design was more cost effective based on material (labour was cheap). Suppliers optimized the Warren truss designs with additional vertical members and / or double intersection designs that were statically indeterminant – a structural analysis problem that was too complicated to be accurately solved using the manual calculation methods then available. However, clever assumptions simplified the analysis to produce results with acceptable accuracy expeditiously (2). Such “enginuity” is recognized in London’s heritage evaluations using the Ontario Heritage Bridge Evaluation Criteria. (*Ontario Heritage Bridge Guidelines – Interim 2008*).

The paper reviews, through four case studies, how heritage evaluation was applied within different mechanisms used by bridge infrastructure managers. The case studies on elderly metal bridges reflect on significant decisions faced by London municipal bridge managers under different circumstances:

- Value vs. maintenance costs
- Public / Municipal Council intervention
- Replacement due to road traffic capacity needs
- Continued use vs. heritage preservation

Case 1 -- King Street Bridge

This 163 foot span Pratt truss bridge on concrete abutments was built in 1897. It served two functions: a transportation connection; and, a support structure for a trunk sanitary sewer which carried effluent to filter beds 2 km downstream. The bridge approaches and sewer were supported by trestles approximately 156 feet long under the west approach and 300 feet long under the east approach across low-lying floodplain. These have since been buried/backfilled with remnants recently unearthed by construction activity.

Figure 3 – King Street Bridge in 1949 (London Free Press)

Figure 4 -- King Street Bridge in 1958 (London Free Press)

In 1947 the bridge was closed to vehicular traffic due to failure of the main deck; a cantilevered sidewalk remained open to pedestrians until 1982. Restoration in that year included removal of the main deck and cantilevered sidewalk before painting. A new main deck was constructed in two separate sections with the sanitary sewer exposed between. Pedestrians were rerouted onto the new main deck sections and the cantilever was removed.

The King Street Bridge has been maintained as a pedestrian crossing while the sewer continues to operate. It had not been considered for heritage designation prior to the project because local conservationists did not have experience with bridges.

As a pedestrian connection across the Thames River, the bridge is an important part of the Thames Valley Parkway, one of London's featured recreational and tourist assets. Situated on scenic park lands, the Thames Valley Parkway is the City’s main multi-use pathway system along the Thames River that connects many of London's neighbourhoods. The current network is approximately 40 kilometres long with several scenic bridge crossings over the Thames River.

A 2008 visual inspection of the King Street Bridge indicated a number of structural and safety concerns. The extent of suggested repairs left bridge managers questioning their value; it was difficult to justify a significant part of the annual bridge rehabilitation program budget being spent on a structure that addressed only active transportation modes (noting that London has over 100 structures to maintain). On the other hand, the sewage-carrying function and recreation value were considered to be high.

Fortunately for the bridge managers, the Province of Ontario was willing to share a budget surplus with municipalities, with a particular focus on transportation infrastructure. This "Investing in Ontario" program was very timely for the King Street Bridge, allowing for a comprehensive rehabilitation program to be undertaken without jeopardizing other important bridge projects.

The rehabilitation work program required:

- Repairs to the concrete barriers, piers and abutments;
- Replacement of the longitudinal steel stringers and connections;
- Coating of the structural steel;
- Reinstatement of the timber deck;
- Replacement of the railing system on the bridge and approaches
- Installation of new wiring, ducts and lighting across the bridge.

The bridge was analyzed utilizing S-FRAME for a pedestrian live load of 3.4 kPa in accordance with the Canadian Highway Bridge Design Code (CAN/CSA S06-06). With a proposed full-width timber deck, the truss was checked for additional live load. Calculations indicated that the capacity of the main truss was sufficient for the additional load.

With time being of the essence for senior government funding expenditures and the bridge not having a heritage designation, formal heritage research, documentation and analysis were not performed. Instead, the engineering design team was assisted by the local community and the City Heritage Planner in researching the history of the bridge to provide a context for the rehabilitation program.

The research yielded pictures showing original bridge features that no longer existed but were related to the pending work program. Most prominent of these were the approaches, deck and handrail. The differences in these items can be seen in the comparative views in Figures 5 to 7.

The design team used the heritage research results to set other objectives -- to recreate visually and with similar materials the “look” of the original bridge while still meeting the technical requirements of the Canadian Highway Bridge Design Code (CAN/CSA –S6).

Of particular note were the design details of the deck and handrail. The original full width deck covered an unsightly sewer. Why it was divided to either side of the sewer is not known, but it is speculated to have been to separate pedestrian bridge traffic and / or to allow for easier visual inspection of the sewer. With the sewer having been structurally relined recently and applying present day concepts for Crime Prevention Through Environmental Design, reverting to the original full width deck made sense.

The original handrail design was found to be a metal lattice of insufficient height to meet present day criteria. Added height to a new, similar lattice handrail was achieved with three cable strands that perform the necessary function but are visually discrete enough to leave the original lattice appearance (Figure 12).

Figure 5 (top left) – Original view

Figure 6 – View Before Rehabilitation

Figure 7 – View After Rehabilitation

Further respect for the historical aspects of this structure included protecting the existing inscription from 1897 on the west abutment (Figure 9) and remounting the existing commemorative plaques, in addition to reinstating some of the original design features noted above (full width deck and railing system). Incorporating these features was intended to bring this structure back to it's vintage appearance, while meeting current structural design requirements.

A fully enclosed negative air system was required to complete the re-coating of the structural steel. The nature of the repair works and recoating of the structural steel required that the bridge be closed to all pedestrian and cyclist traffic for the duration of the project. Total construction cost was $1.4 million. Figures 8 to 13 provide various views of the project.

Figure 8 – Abutment Restoration

Figure 9 -- Retained Abutment Inscription

Figure 10 -- Elevation

Figure 11 – Night View

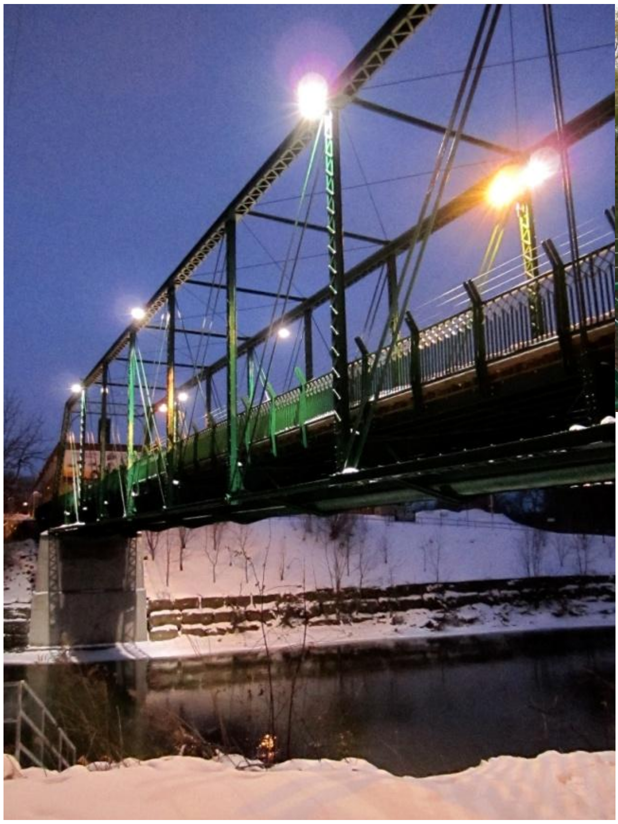


Figure 12 – Handrail and Deck Details

Figure 13 – Portal View During Construction

Case 2 -- Meadowlily Bridge

Meadowlily Bridge is a structure of growing heritage interest in the City of London. Erected in 1910/11, the multi-span steel structure consists of three spans over the south branch of the Thames River: two pony trusses of 26.2 and 22m over the floodplain, and a 42.3m Double-Intersection Warren truss spanning the main river channel. Originally designed to carry vehicular traffic, it has been reduced to pedestrian-only traffic confined to the centre 1.5m of the bridge. Regular inspections have reported the superstructure to be in fair to poor condition with some truss members and particularly the floorbeams having large sectional corrosion loss. In 2008 it underwent emergency measures to support the two pony trusses due to floorbeam deficiencies. Steel bents on concrete footings were constructed to prevent potential failure of the deteriorated floorbeam webs and gusset-plate connections.

Figures 14 – Elevation

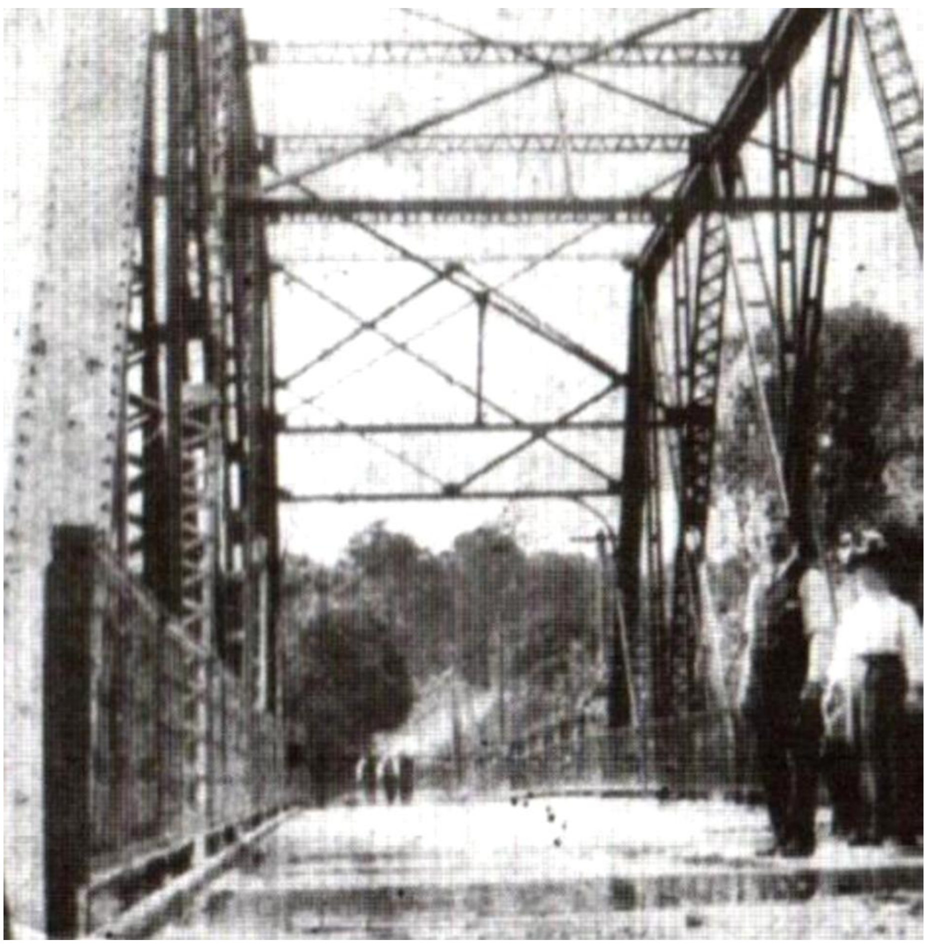
Bridge management engineers proposed an Environmental Assessment Study that would engage the public in a review of alternatives. Such assessments can include a wide variety of options, including "do nothing", replacement and alternative uses (e.g., a return to vehicular traffic). Concurrently with staff recommendations on such broad considerations for the bridge site, the London Advisory Committee on Heritage and local community advocates declared their interest to list the bridge in the Inventory of Architectural and Historical Heritage Resources within the City of London. The Municipal Council responded to these initiatives with a number of resolutions that clearly indicated a desire to designate the bridge, to not consider a replacement option and to maintain a pedestrian bridge "in perpetuity". This effectively narrowed the scope of future possibilities for the river crossing to repairing and designating the existing structure, which bridge engineers recommended be confirmed with a technical study.

The heritage component of the technical study was a significant effort because no previous research on this bridge had been consolidated for evaluation. In addition to research on the historical context for the river crossing, previous structures at the same location, notable people involved and bridge life history documentation, bridge managers asked specifically for a review of the engineering science heritage associated with the bridge.

Results of the Cultural Heritage Evaluation Study (1) confirmed the Meadowlily Bridge to be of significant heritage value because it:

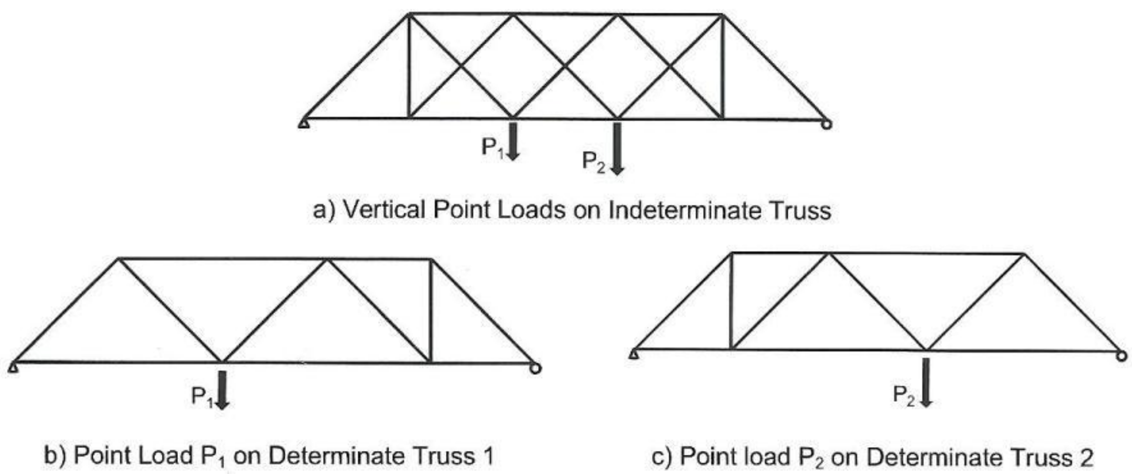
- Is an increasingly rare survivor of a once common truss – the Double-Intersection Warren truss;
- Was built by a locally known contractor – Levi Crouse – and the Hamilton Bridge Works Company;
- Provided access to a mill for local farmers (ruins of the mill and headpond exist upstream);
- Is a local community landmark within the Meadowlily Natural Reserve and Meadowlily Woods Environmentally Significant Area; and,
- Has an Ontario Heritage Bridge scoring of 74.

Figure 15 – Opening Day, 1911



Bartlett and Scott (2) documented the engineering heritage of the bridge with a focus on how engineers over 100 years ago were able to analyze the statically indeterminate Double-Intersection Warren Truss. The graphical methods at that time used superposition to simplify the analysis. Engineers considered the structure as two statically determinate trusses as shown in Figure 16, with loads acting independently at panel points. Chord forces were determined by adding the results from each truss. They compared historical method results to modern computations with a structural analysis computer program and found results quite comparable. Double intersections were introduced into the Warren truss to increase the number of joints along the bottom chord, effectively reducing the loading and size of stringers and floorbeams. At that time, steel as a fabricated material was more expensive than the labour cost to fabricate and erect it -- and the weight of the stringers and floorbeams often approximately equalled the weight of the trusses.

Figure 16 – Analysis of Double-Intersection Warren Trusses (2)



An engineering technical study was required to develop a detailed understanding of the structure to confirm that it could be rehabilitated. A thorough structural investigation (3) included material testing (concrete cores and steel tensile test specimens), manual and ultrasonic measurements of truss members, condition rating, details of riveted connections and structural analysis.

It was concluded that the Warren truss main span could be rehabilitated to support pedestrian loads subject to: bearings being replaced; replacement or strengthening of localized members; and, coating of the steel.

Figure 17 – Top View

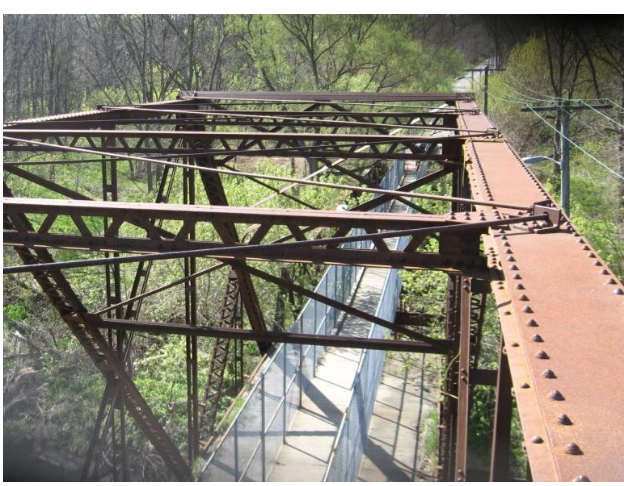


Figure 18 – Bearing

Figure 19 – Pony Truss Floor Beam Connection

The two pony trusses were in severe condition, leaving alternatives of rehabilitation or replacement both open for further consideration. If rehabilitation was to be considered, then a significant program was needed: replace floor beams and connections; replace bearings; replacement or strengthening of localized members; temporary support; and, coating of the steel.

Alternatively, the pony trusses could be replaced with visually similar trusses, a girder design or a proprietary pedestrian bridge truss selected from a catalogue. It is interesting to note that 100 years after the original structure was selected from a catalogue that bridge managers still have that same option available to them!

Concrete piers and abutments were found to be in fair to poor condition. However, without any settlement, undermining or other apparent distress, they were recommended for continued use with simple removal of unsound concrete and re-facing. The concrete deck on the main span was found to be beyond repair, leaving replacement material options as a detailed design consideration. Fortunately, the reinforced concrete deck has little heritage significance except for two stamped names. This part of the deck was recommended for salvage and preservation.

With the structure and its heritage well understood, the study team approached the unanswered rehabilitation / replacement options with a quantitative assessment of three alternatives.

Historic Restoration using classic materials and connections (rivets).

Sympathetic Restoration using modern materials and visually similar connections (round head bolts) for repairs.

Replacement of Pony Trusses and sympathetic main span repairs.

A Sympathetic Restoration was selected as the best alternative (3). Remarkably, it proved to be superior in comparators involving cost, constructability and environmental impacts. Historic Restoration, though rated highest for heritage preservation, carried risks associated with skilled labour, non-destructive testing of connections and uncertain (and higher) costs. The *Replacement of Pony Trusses* alternative rated highest in meeting modern requirements and life expectancy, but was the least desirable from a heritage viewpoint, environmental impacts and cost.

The study team and City bridge managers had confidence in the recommendation because of their recently completed work on rehabilitating the King Street Bridge (also covered in the paper). At the time of writing the paper, approval to proceed with the project as recommended was given by the Municipal Council with funds approved in 2012 for the $1.9 million project. Construction is expected in 2013.

Case 3 -- Sarnia Road Bridge

Significant growth in northwest London was driving the need for transportation capacity improvements. Sarnia Road was a two-lane arterial road that could provide east – west capacity, but was constrained by a single lane bridge over Canadian Pacific Railway (CPR).

Figure 20 – Study Site (4)

The road existed before CPR constructed their track in 1889; under a Board Order, they had been 100% responsible for maintaining the crossing. Their bridge (Figure 21) had constrained road capacity to less than 7,000 vehicles per day. However, the City required a 9,500 vehicle per day capacity by 2017 and further increases after that.

CPR believed that their overhead structure was approaching the end of its useful life. It had required ongoing investment to repair its deck, and the sharp approaches (Figure 22) and single lane width (Figure 23) had led to two commercial vehicle collisions with the bridge that closed the road for a total of five months. Permanent shoring, clearly visible in Figure 21, was installed.

To plan for a future four lane road, an Environmental Assessment (EA) Study and Preliminary Design (4) was undertaken in 2009 with a study area covering 2.4 km of the road, including the CPR overhead crossing. Environmental Assessment studies require heritage consideration.

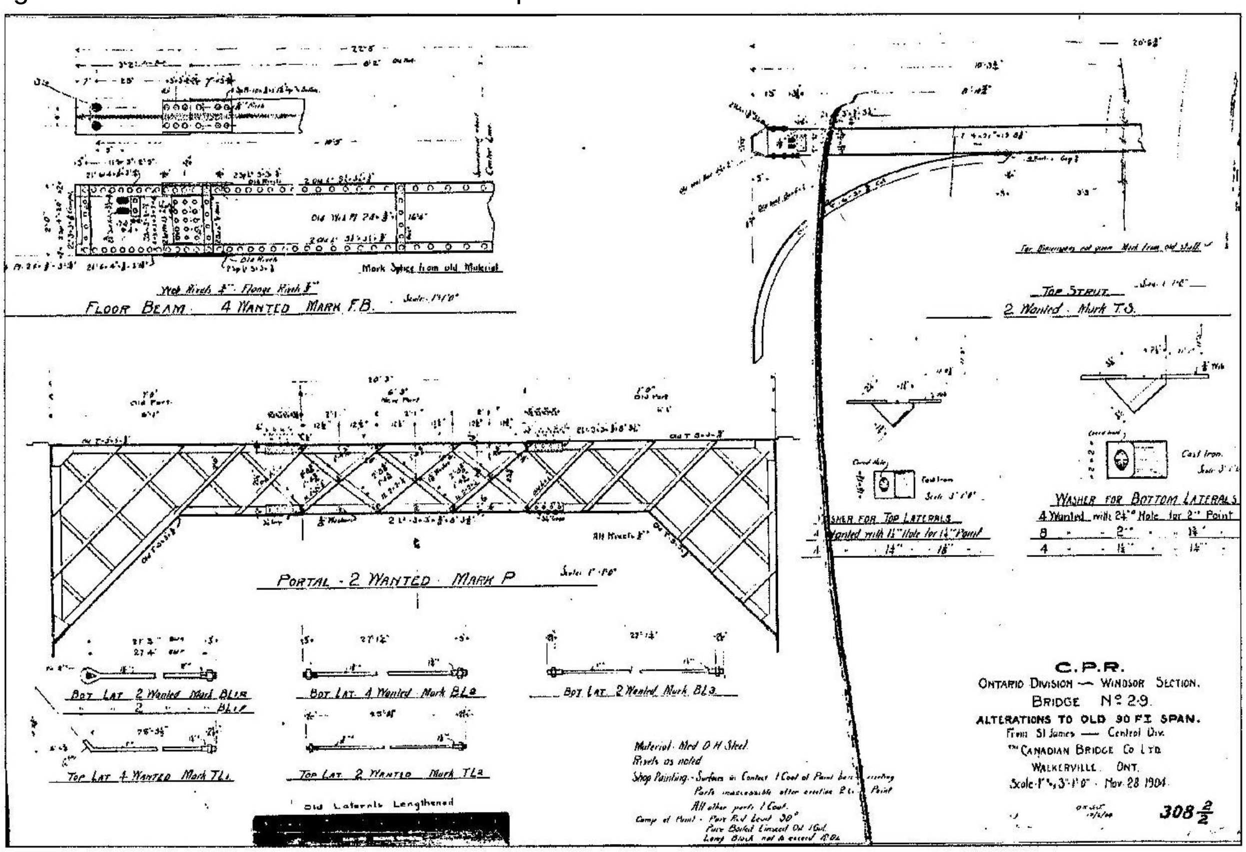
Figure 21 – Elevation

Figure 22 – Bridge Approach

Figure 23 – Single Lane Operation

The rail line was constructed in a deep cut by the Ontario Quebec Railroad Company in 1889. The first bridge on the site accommodated the high skew angle of the road to rail alignments with a 296 foot timber structure. It was replaced in 1909 with a 90 foot steel, pin connected Pratt truss that had seen previous service as a rail bridge in St. James, Manitoba (5). The conversion to road use involved numerous structural modifications to increase the portal to 20 feet. Close inspection and structural drawings (Figure 24) revealed splices and re-use of materials. The crossing span length was significantly reduced by re-aligning the road approaches to allow for a 90 degree crossing. As noted above and shown in Figure 23, this led to one lane operations and presented a collision hazard.

Figure 24 – "Alterations to Old 90 Foot Span"



This structure was already recognized in the City of London's Heritage Inventory as a Priority 2 heritage resource. Priority 2 resources have significant architectural / historical value and warrant designation under Part IV of the Ontario Heritage Act on application by the owner (in this case, CPR). By comparison, a Priority 1 designation deserves more consideration, while a Priority 3 designation does not require a rigorous response.

Results of the Cultural Heritage Evaluation Study (5) confirmed the Sarnia Road Bridge to be of significant heritage value because it:

- was a rare survivor of a once common Pratt truss bridge;
- was relocated from Manitoba and modified to suit its new purpose;
- was associated with the CPR, settlement of the local Township and a long history of transportation service to it,
- had an Ontario Heritage Bridge scoring of 70.

With the structure heritage well understood, an assessment of conservation strategies guided by the EA Cultural Heritage Evaluation was undertaken to arrive at a preferred option. Three general approaches were evident:

- Design a new crossing such that the heritage bridge could remain in place;
- Relocate the bridge to a nearby or remote site for alternative use; or,
- Document and demolish the structure, and include sympathetic design features in the new structure.

Retention

The Sarnia Road EA evaluated numerous options to address the road operating deficiency presented by the current bridge. This included an option to retain the historic bridge at its current location. However, analysis determined that this option would add $3.8 million to the project cost, and incur significant property impacts. This alternative was not recommended. The new bridge required removal of the existing bridge from its current location.

Relocation -- Nearby on CPR Line

The mitigation measures recommended for potential relocation strategies included a feasibility assessment by an engineer, selection of a new site that had ties to CPR and erection of a plaque.

Relocation near the current site along the CPR line was initially dismissed because CPR was planning for a second rail line along the corridor – the bridge is not long enough to span a double track corridor. However, CPR later indicated a one-track crossing would be sufficient. This made an on-site relocation option feasible and led to some preliminary engineering to evaluate this option.

Relocating the bridge to the east of the new structure was possible. It would involve lifting the bridge off its abutments and placing it in a temporary lay-down area for recoating. The bridge would be placed on newly constructed abutments followed by minor repairs and installation of a new deck and railing. It would serve as an alternate pedestrian crossing of the CPR tracks. A landscaped sidewalk to create a path for pedestrians to gain access would also be needed. However, bike lanes and sidewalks would also be constructed continuously across the new structure; pedestrians would likely choose this route as a shorter alternative to the relocated bridge.

The estimated cost of this option was $1.28 million. Although the relocation distance for this option was relatively short, the total estimated cost was high due to the requirements for a "new" railway crossing. The foundations would be substantial.

Additionally, this option carried significant risks. Placing the bridge at a new location across the tracks would require a new legal agreement with CPR. Approval of the relocation design would have been required and the project would have been subject to requirements imposed by the railway. Because this alternative had been previously eliminated, no further detailed discussions or engineering reviews had been carried out with CPR.

Ongoing maintenance and rehabilitation obligations would include snow removal, periodic minor structure and deck repairs, and recoating every 25 years. These costs would be sporadic over the life of the structure. For comparison purposes, maintenance and rehabilitation were translated into an equivalent annual cost and was estimated to be in the range of $10,000 per year. Ongoing maintenance would also have been subject to CPR scrutiny and would have been at risk of increase.

Relocation – Abandoned Rail Spur Line

Relocation alternatives were exhaustively investigated but capital costs remained high. Ongoing maintenance and rehabilitation was assumed to be less for a non-functioning location at $7,500 equivalent annual cost as compared to $10,000 for a functional site.

The most suitable location identified was a multi-use path on a nearby abandoned rail spur line. This option involved lifting the bridge off its abutments, disassembly at a nearby lay-down area, recoating and transport to its new location. The bridge would be re-erected with minor truss repairs, and placement of a new deck and railing on new abutments and approaches. The cost of this alternative was estimated at $950,000 for a water-crossing location and $790,000 for a non-functional locational. The appeal of this option was considered to be low given that the bridge would have little or no bridge function. The costs were deemed to be excessive for a non-functioning artifact.

Removal

Figure 25 -- Truss Bridge Crane Lift

This option comprised lifting the truss bridge off its abutments (Figure 25) and placing on a lay-down area for documentation and disassembly, with subsequent storage of bridge members for an as yet unknown purpose. This was the most economical option at $150,000, and least risky. Heritage conservation was conducted following the mitigation measures outlined in the EA Heritage Evaluation, including incorporation of sympathetic design elements into the replacement structure, full documentation of the steel truss structure prior to removal and erection of a plaque. The crossing replacement project is further shown in Figures 26 to 30.

Figure 26 – Final Alignment (4)

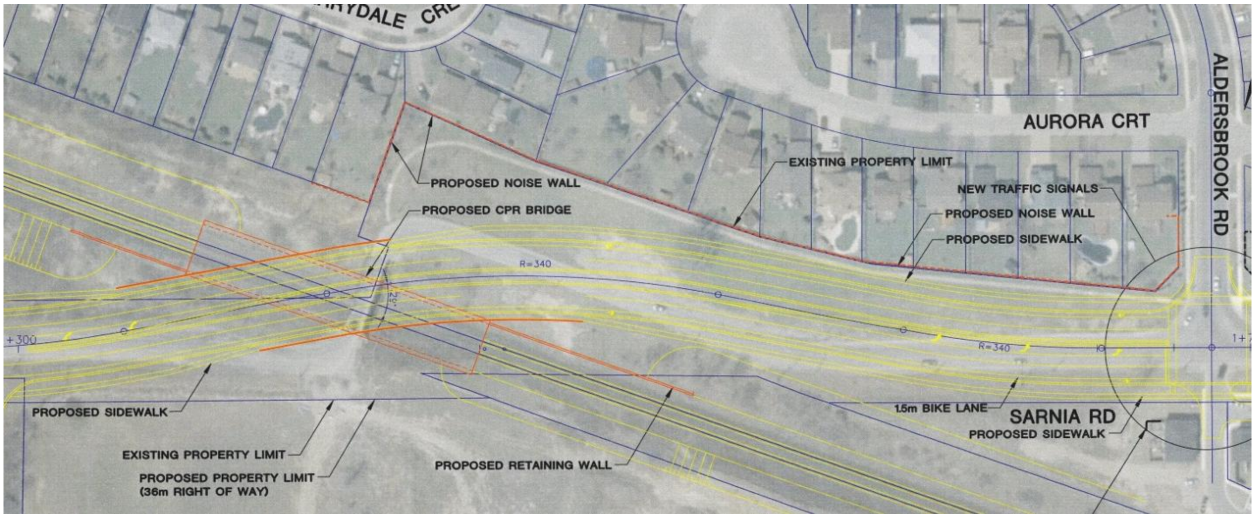


Figure 27 – Girder Placement

Figure 28 – "Sympathetic" Wall Detail

Figure 29 – New Crossing Alignment

Figure 30 – CPR Portal

Case 4 -- Blackfriars Bridge

Blackfriars Bridge was a local Public Works first when it was opened for service on Monday, September 27, 1875. It was the first metal bridge erected in the London area, and provided a clear span of 216' (65.8 m) with a maximum height at midspan of 25'-6" (7.8 m). Previous wooden bridges at this central, downtown crossing of the North Thames River as shown in Figure 31, needed intermediate supports, which invariably washed out when the Thames exerted its will during spring freshets, or succumbed to rot. The Victoria Bridge at the south end of Ridout Street over the Thames South Branch was the Blackfriars "sister" when erected in the same year, surviving until 1926. Both were structures purchased from the Wrought-Iron Bridge Company (WIBC) of Canton, Ohio. These bridges were well within the 50 to 350' (15 and 105 m) product line that the company offered. Isaac Crouse, a local timber bridge builder, prepared the stone abutments. (7)

The uniqueness of the 137 year old Blackfriars Bridge can be derived from a recent Cultural Heritage Evaluation Report (7) which included a list of "the wrought iron bowstring arch-truss bridges fabricated and erected by the Wrought Iron Bridge Company (WIBC) that are believed to be in existence in Canada and the United States. According to these

Figure 31 – Earlier Blackfriars Bridges (6)

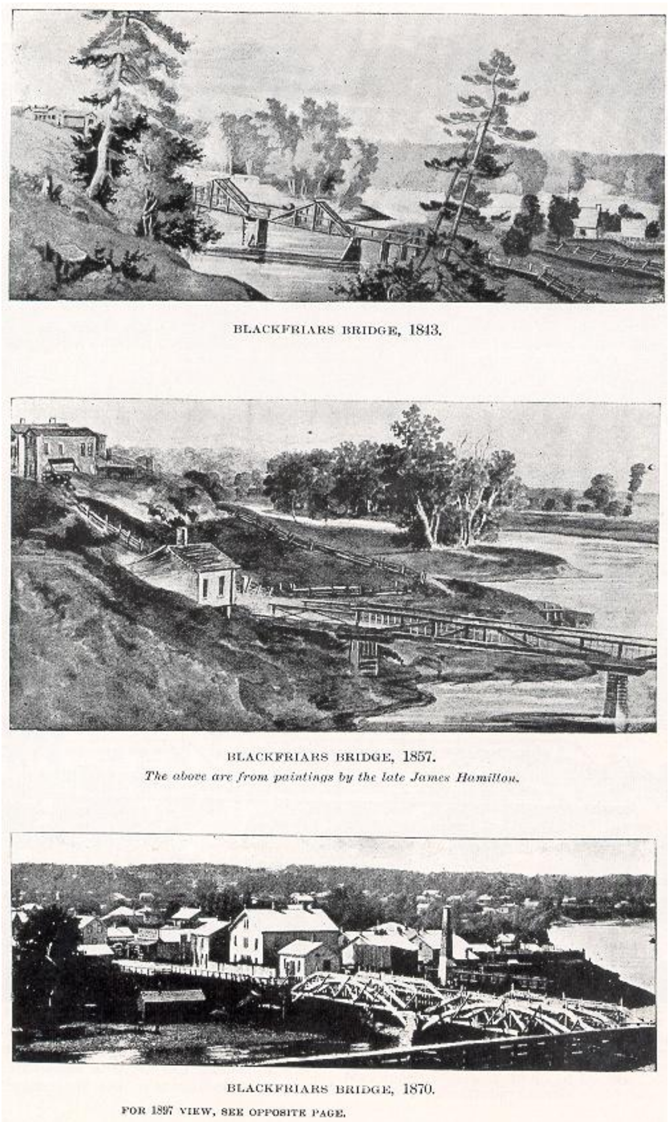
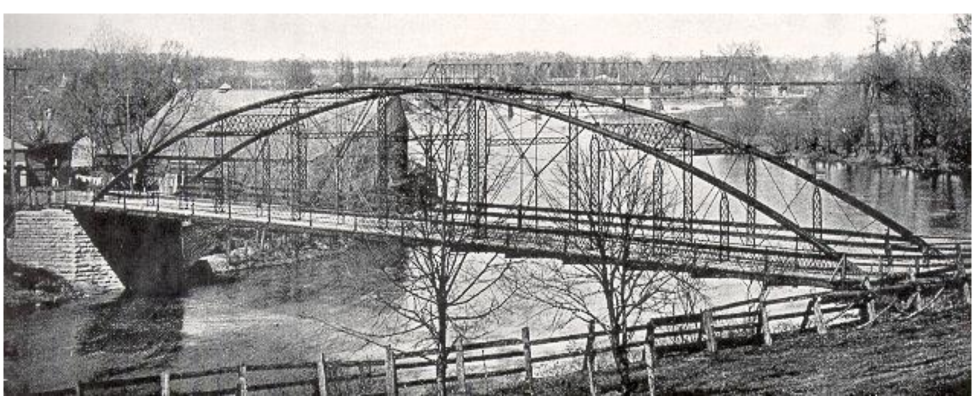
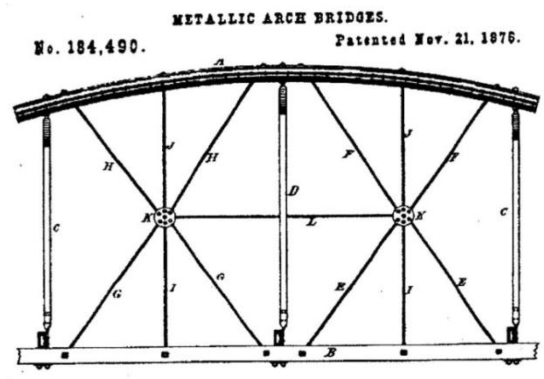


Figure 32 – Blackfriars Bridge in 1900



data, the Blackfriars Bridge is: "the only WIBC Bowstring Arch-Truss in Canada; the longest-surviving WIBC Bowstring Arch-Truss; one of only four surviving structures still carrying vehicular loads; and the only remaining structure open to two lanes of traffic. Of the 19 WIBC bowstrings still in existence, three are stored, seven are closed or abandoned, and five are pedestrian-only bridges."

Figure 33 -- "Improvement in Metallic Arch-Bridges" (U.S. Letters Patent No. 184490) (9)



Blackfriars Bridge is a bowstring arch-truss bridge, and it should have defied designers' structural analysis capabilities in the 1870s given it is statically indeterminate to the thirteenth degree. It also features a double-panel diagonal detail that was patented in the United States (Figure 33), a year after the bridge was constructed. How engineers of the day could have managed this problem was the subject of research by Bartlett, Graham and Camiletti (8). Their work determined that the designers could have analyzed it as a truss with sub-panels, but their patents say that the participation of verticals is important. If this is to be believed, they couldn't have analyzed it given the tools of the day, and the method they would have tried to use doesn't seem to be entirely accurate.

Records of bridge maintenance date back to 1948. It was load restricted to 5 tons in 1949 and further reduced to 3 tonnes in 1986. Significant work to strengthen truss members and reduce vibration was completed in 1951/52. The most effort since then has been on repairs to the wood deck. To maintain a low dead load, a 2x4 nail laminated deck has been used, but is subject to rot, localized failure and frequent maintenance.

The bridge has exceeded the usual 75 - 100 year service life of bridges, something not likely expected by the City Engineer of the day, William Robinson. The bridge functions as an alternate vehicular traffic river crossing to Downtown London. A high volume of traffic and speeding pose significant risks to the structure, the bridge's cultural heritage significance and, bicycle and pedestrian traffic in the neighborhood. It was designated in 1992 as an Ontario Heritage Structure and is a common subject for local painters and photographers.

Figure 34 – Elevation

Figure 35 -- Portal

The future of the bridge lies in pending decisions. How much longer can it survive with vehicles using it daily? Collision and washout are the two main reasons for the loss of heritage bridges; the bridge is exposed to both. As an aging structure, it continues to need repairs, even though it can only support light vehicles. What is the best way to retain its heritage value and what function does this suggest?

Bridge managers have determined the best way to answer these questions and prepare for the long term is by means of a risk assessment. A thorough understanding of the bridge's role, condition, exposures and capabilities is needed. At the time of writing the paper, a multi-component study is in progress (10) that makes use of disciplines and experts in these fields:

- Structural Engineering
- Transportation Planning and Traffic Engineering
- Drainage and Hydrology
- Cultural Heritage Planning (bridge and landscape)
- Land Use Planning
- Risk Analysis

The Risk Assessment is intended to be the first phase in the development of a long-term strategy to protect the bridge, and its significant heritage and aesthetic value, all in balance with its function as a Thames River crossing. The goal is to clearly understand the risks inherent in the current management of the bridge through considering a range of possible, uncertain events and their consequences should bridge managers maintain the status quo for the Blackfriars Bridge.

To start the study, a framework in the form of a general Risk Profile (10) was developed for the Risk Assessment. Being a measure of the City's appetite for risk, the Profile can support any municipal risk assessment application. A cross-section of staff from many City Departments participated in defining a range of consequence measures for eight risk categories:

<u>Risk Categories</u>	<u>Range of Consequences</u> (severity of a possible event)
Public Safety	
Employee Safety	minimal
Environmental	marginal
Financial	serious
Reputation	critical
Legal & Regulatory	catastrophic
Service and Productivity	
Technological Issues	

In the private sector all measures of severity are in financial terms. However, this did not match the measures of success or failure in the public sector, in the opinion of the staff involved. A number of the measures will be non-financial in the London Risk Profile. Typical examples: a *catastrophic* Financial consequence will be *more than $10,000,000*; a *serious* Public Safety consequence will be a *serious injury, multiple injuries or an evacuation*; and a *minimal* Employee Safety consequence will be first aid or minor medical treatment.

A measure of probability is also required to conduct the Risk Assessment. Frequency can be in qualitative terms:

Probability Categories	Frequency Description	Probability
Improbable	hasn't happened before anywhere	very low
Remote	has happened somewhere before	low
Occasional	can/could happen here	medium
Probable	has happened here before	high
Frequent	happens often	very high

Completion of the risk assessment will use topic experts, who have already delved deeply into structural, traffic, hydraulic, cultural and planning aspects of the bridge and its environs. In a workshop setting, they will assist London staff with identifying risks, setting their consequences and frequencies, and building a measure of risk based on:

Risk = Frequency x Severity

Risk Treatment analyses will follow this, with the team assessing options to reduce, eliminate or accept identified risks. These are the results needed for future work that will develop a long term management plan for the bridge with public participation.

Summary

Four different situations faced London bridge managers involving older metal structures that had varying levels of heritage documentation and public interest. In each case, cultural heritage research and documentation provided a context for significant decisions.

King Street Bridge (1897) required significant rehabilitation and had not been considered for heritage designation. In this case, even though a formal Cultural Heritage Evaluation was not undertaken, sufficient information about the original features of the bridge allowed the design team to set design objectives and make decisions about visual and functional elements of the bridge. The sympathetic design approach used in the rehabilitation project dramatically improved the aesthetics and function of the bridge.

Meadowlily Bridge (1911) was facing a possible demolition and had not been designated, but community interest resulted in a Municipal Council direction to do so. A formal Cultural Heritage Evaluation indicated a high heritage value. It was used to rationalize a rehabilitation program in conjunction with detailed inspection, material testing, member measurements, structural analysis and condition rating. A sympathetic restoration program was recommended and is in progress.

Sarnia Road Bridge (1909) was a traffic bottleneck in a growing part of London. It held a Priority 2 heritage designation, meaning the owner (CPR) could apply for designation (which, perhaps significantly, they had not acted upon). In this case, a formal Cultural Heritage Evaluation was required to be undertaken within an Environmental Assessment study for road improvements. Sufficient information about the bridge allowed the design team to fairly assess the costs, benefits and risks associated with a hierarchy of conservation approaches. Notwithstanding a high heritage value for the bridge, a demolition option was accepted by the Municipal Council and local conservation advocates. The new bridge (2011) incorporates visual elements of the original Pratt truss bridge, and commorative plaques. The steel from the original bridge remains in storage for possible re-use.

Blackfriars Bridge (1875) is a prized landmark with a questionable future because of risks it is exposed to. A risk assessment study is in progress to quantify its exposure and to arrive at a new management plan (function, purpose and maintenance regime). Even though the Blackfriars Bridge is already heritage-designated, the historical documentation was found to be fragmented. The bridge managers desired a document that would be the compendium of history on the bridge, including engineering design. This strong heritage foundation set a high value for the Blackfriars Bridge, which may be required to offset possible and significant operational changes within a new bridge management plan. The role of an updated Cultural Heritage Evaluation in this case is critical to setting a measure of consequence for the risk assessment. As a functioning bridge, the transportation measure of its loss would be the replacement cost. The social cost, though, would be much higher and not likely found in monetary terms. A credit card advertisement would call it “priceless”.

A complete understanding of each bridge established values beyond just the monetary. Whether a formal heritage investigation was required or not in the four cases reviewed, the various levels of research played a role in significant project decisions, including design detail development, conservation approach evaluation, a demolition decision and consequence definition for a risk analysis.

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