APPENDIX B – FIRE RISK ASSESSMENT FOR STRUCTURES

Background

The purpose of this document is to outline the procedures for conducting fire risk assessment for bridges, as a supplement to the *Illinois Tollway Structural Design Manual* (SDM). The methodology is based on and adjusted from Journal of the Transportation Research Board 2016 article “Fire Risk Assessment for Highway Bridges in South Korea (article 2551)”, and the 2018 memorandum titled “Central Tri-State Fire Protection, February 26, 2018”. The tool is a spreadsheet that may be downloaded from the Illinois Tollway’s internet site at www.illinoistollway.com, under Construction & Engineering, Consultant Resources, Manuals, Bridges & Structures, and it shall be used during the Concept Phase. Snapshot images of the parts of the spreadsheet are provided in the body of this document, highlighting examples of its use. The mechanics of the calculation are explained by an example application. Refer to the SDM for general guidelines on applicability of risk assessment.

Method

For a given bridge, there are three possible tiers of risk assessment it may undergo (in order of completion):

1. Preliminary Risk Analysis (PRA)
2. Simplified Risk Analysis (SRA)
3. Detailed Risk Analysis (DRA)

The benefit of this tiered assessment structure is that a screening process can be used to efficiently filter out bridges deemed to be at a LOW risk level, and more time can be focused on bridges with greater possible risk, through answering a series of increasingly detailed questions. Bridges at a LOW risk level skip the Detailed Risk Analysis (DRA) and/or the Simplified Risk Analysis (SRA). The DRA is a detailed, bridge-specific analysis potentially involving (but not limited to) computer simulations, structural analysis, and design mitigations (such as, for instance, passive fire protection). It is reserved for bridges evaluated to be at an overall HIGH fire risk level, based on SRA (with exception of question 1 in the PRA, which requires a DRA if the bridge length is more than 1000 feet, regardless of potential risk level).

Figure 1 shows the hierarchy of risk assessments. Figure 2 shows the cover page of the risk assessment calculation sheet.

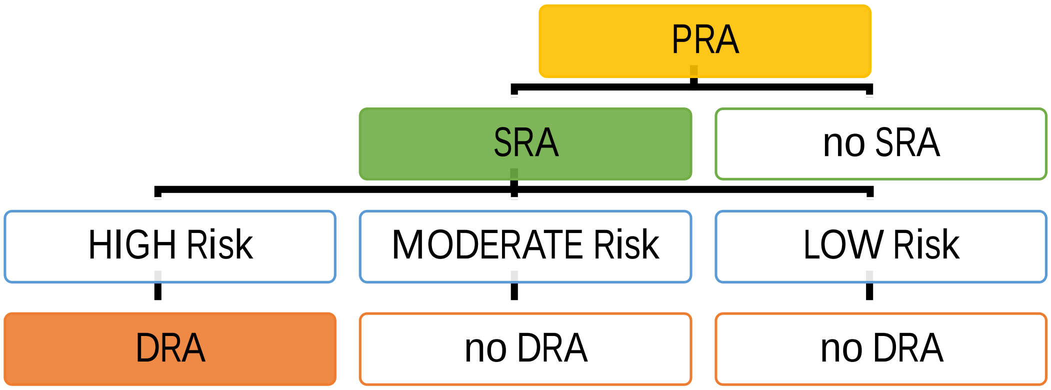

Figure 1: Hierarchy of risk assessments, with names of risk assessment tiers in solid colors

THE ILLINOIS STATE TOLL HIGHWAY AUTHORITY

RISK ASSESSMENT OF BRIDGE COLLAPSE DUE TO FIRE

Prepared By:	XYZ	Prepared On:	11 Jan, 2020
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Bridge No.	175	IDOT Structure Number:	016-9826

This risk assessment tool performs Preliminary and Simplified Risk Analyses for bridges to determine which structures require additional fire protections. The basis for this tool is further explained in the Illinois Structural Design Manual for fire protection.

Inputs are in blue. Non-inputs (referenced information) are in yellow boxes.

This worksheet is FOR PRINT / view only. Selection of parameter inputs are done on another sheet.
The only manual input on this sheet is the Bridge No. Based on this, the risk scores for the corresponding bridge are presented below.
The overall fire risk score and recommendations for mitigating fire risk are summarized at the bottom of this sheet.
Note that this assessment is not developed for suspension, cable-stayed or other complex bridges; it is intended for typical concrete or steel girder bridges. The principles could be applied to other bridge structures, but a consideration of how a fire hazard on the bridge would impact key structural elements would need to be made.

Figure 2: Example risk assessment sheet cover page

Note: This assessment method is not developed for suspension, cable-stayed or other complex bridges; it is intended for typical concrete or steel girder span bridges. The principles could be applied to other bridge structures, but a consideration of how a fire hazard on the bridge would impact key structural elements would need to be made.

Step 1: Preliminary Risk Analysis (PRA)

Preliminary Risk Analysis (PRA) makes a quick assessment (result is a go/no-go status) of whether the bridge is at a concerning level of risk based on three questions which require binary (yes/no) answers:

1. Is the bridge length greater than 1000 feet?
2. Is the vertical clearance of the bridge less than 84 feet or is there potential for flammable materials near critical structural elements (like supporting columns)?
3. Is there potential for truck accessibility, railroad accessibility, and/or storage of flammable materials under or over/on the bridge?

Note: The bridge height of 84 feet is informed by CFD analysis reported in the TRB article "Fire Risk Assessment for Highway Bridges in South Korea (article 2551)," which recommended a bridge height threshold of 56 feet. A margin of 50% was added to the 56 feet, giving a value of 84 feet. More advanced CFD analysis (using a software and methodology validated to accurately predict peak fire temperatures), specific to the bridge and fire scenario in question, would be necessary to consider a lower threshold (than 84 feet) for clearance height.

Answers to the PRA questions will determine whether the bridge needs further analysis via Simplified Risk Analysis (SRA):

- If the answer is to question 1 is “YES,” then the bridge needs to be evaluated in detail with both SRA and DRA; using SRA to identify critical risk areas.
- If the answer to question 1 is “NO”, but the answer to both question 2 and 3 is “YES,” then proceed to SRA. Otherwise, the bridge does not require further risk analysis. The underlying assumption behind question 2 and question 3 is that bridges with a low clearance height and possibility of exposure to flammable materials or fuel loads are at a concerning risk level and in need for further analysis.
- Flammable materials that can cause bridges to be exposed to fire include (but are not limited to) heavy goods vehicles, liquid tankers, wood pallets, large quantities of regular combustible goods, and any anticipated hazardous material cargo.

Preliminary Risk Assessment (PRA)		**NFPA 502 4.3.1 Item**
1) Is the bridge length greater than 1000 feet?	No	
If "Yes", a Detailed Risk Analysis shall be performed. Perform the Simplified Risk Assessment to identify the cause and risk level.		
If "No", the need for a Detailed Risk Analysis shall be determined based on the Preliminary Risk Assessment and Simplified Risk Assessment.		
2) Vertical Clearance height under bridge < 84' or potential for flammable materials near critical structural elements	Yes	Item(s): 16
3) Truck/Railroad Accessibility/Storage of flammable materials over/under/on the structure	Yes	Item(s): 4
If both above are "Yes", continue to Simplified Risk Assessment.		

Figure 3: Example of PRA leading to SRA

Step 2: Simplified Risk Analysis (SRA)

Simplified Risk Analysis (SRA) makes an evaluation of bridge risk level (result is an overall fire risk level) by asking three sets of questions which require ranked answers (low, moderate, high) pertaining to the condition and risk profile of the bridge. The questions fall into one of three subject categories: probability of fire occurrence, structural vulnerability, and economic/social importance of the bridge. Within each category there are sub-categories that feed into development of an overall score.

SRA: Occurrence

Occurrence gauges the likelihood of a bridge fire event and uses the following sub-categories and proportional weighting (in parentheses) to develop an overall score for Occurrence:

- Transportation mode under the bridge (30%)
- Potential for storage of hazardous materials under the bridge (30%)
- Volume of truck traffic under the bridge (30%)
- Accident history under the bridge (10%)

The proportional (percentage) weightings are determined as follows:

- Percentages are subject to the risk auditor’s qualitative judgement of each criterion’s significance to fire risk and can be adjusted only where a clear case is made and approval is received from the Illinois Tollway.

- In general, it is not recommended to deviate from the values already set herein unless justification is given, and changes are approved.
- As a reminder, comparison of changes to risk scores and levels (for reassessments) are only valid when weightings for each criterion remain consistent.

Each sub-category is given a rank of LOW, MODERATE or HIGH and a score is assigned accordingly (1=LOW, 2=MODERATE, 3=HIGH). The overall Occurrence score is then calculated based on the sub-category proportional weighting multiplied by the sub-category score. Figure 4 shows an example. In this example the overall Occurrence risk is LOW, based on the following calculation:

- 2.0 * 0.3 (transportation mode) + 1.0 * 0.3 (storage) + 1.0 * 0.3 (volume of traffic) + 2.0 * 0.1 (history) = **1.4 (LOW)**

Note that the overall score is classed as LOW based on the following ranges:

- LOW (1.0 ≤ SCORE < 1.5)
- MODERATE (1.5 ≤ SCORE < 2.5)
- HIGH (SCORE ≥ 2.5)

Occurrence	**NFPA 502 4.3.1 Item**		
Transportation modes under the bridge/roadway classification	Item(s): 2		
Type of route			
Low: Rural Roadway Moderate: Suburban Roadway; Rail Line High: Urban Roadway; Rail yard	Moderate	Value = 2	Weight = 30%
Storage	Item(s): 6a, 20		
Assign risk level based on the potential for storage of combustible items beneath the facility.			
Low: No storage beneath structure - barricades/slopewall present. Moderate: Potential for storage of limited quantity of hazardous or combustible materials High: Potential for storage of high quantity of hazardous or combustible materials	Low	Value = 1	Weight = 30%
ADTT Under Bridge	Item(s): 3, 6b, 18		
Amount of truck traffic beneath the bridge correlates to risk level of a large incident that could damage the bridge.			
Low: Less than 4,700 Moderate: 4,700 to 17,500 High: Greater than 17,500	Low	Value = 1	Weight = 30%
Accident History Beneath the Bridge	Item(s):		
This data is currently assumed.			
Low: None Moderate: <3 High: 3 or more cases	Moderate	Value = 2	Weight = 10%
BASED ON ABOVE INPUT - OVERALL OCCURRENCE RISK:	**Low (1.40)**		

Figure 4: Example of calculation of risk of fire Occurrence

SRA: Vulnerability

Vulnerability gauges the characteristics of the bridge that would potentially be influenced by a fire event. The method of computing the Vulnerability score is the same as the Occurrence category outlined above (score of 1=LOW, 2=MODERATE, 3=HIGH, weightings applied to determine an overall score), but there are additional categories that factor into the score. Figure 5 show the example calculation. The following categories are applied:

- Superstructure type (15%)

- Span configuration (10%)
- Vertical clearance height (40%)
- Bridge maintenance/health index (15%)
- Design live load (10%)
- Emergency communication to appropriate agencies and first responders (2%)
- Emergency response time and distance to local fire department (2%)
- Emergency vehicle access beneath the bridge (2%)
- Water access for fire suppression (2%)
- Drainage system characteristics (2%)

Vulnerability		NFPA 502 4.3.1 Item	
Superstructure Type		Item(s): 7, 16	
Low: Reinforced concrete Moderate: Pre-stressed/Post-tensioned concrete High: Steel	High	Value = 3	Weight = 15%
Span Configuration This characteristic accounts for the redundancy of the structure.		Item(s): 16	
Low: Rigid frame Moderate: 3 or more spans continuous High: Simple or 2 spans continuous	High	Value = 3	Weight = 10%
Vertical Clearance Height As the vertical clearance increases, exposure to heat from fire beneath the bridge is reduced. Before modifying threshold values, validated CFD analysis for fire temperature exposure needs to be conducted.		Item(s): 7, 16	
Low: Greater than 84' and no flammable materials near key structural elements Moderate: Greater than 56' and less than 84' and no flammable materials near key structural elements High: Less than 56' or flammable materials stored near key structural elements	High	Value = 3	Weight = 40%
Bridge Maintenance/Health Index Health index is a weighted representation of the condition ratings of the deck, superstructure and substructure. (100 is excellent condition) Bridges with a higher health index are in better condition and will have additional capacity to resist damage from heat.		Item(s): 7	
Low: Health Index greater than 85 (satisfactory condition or better) Moderate: Health index between 70 and 85 (fair condition) High: Health Index less than 70 (poor condition or worse)	Low	Value = 1	Weight = 15%
Design Live Load Bridges constructed for higher loads will have additional capacity to withstand damage from heat.		Item(s): 7	
Low: IL-120 Moderate: HS20 High: Less than HS20	Moderate	Value = 2	Weight = 10%
Emergency Communication to Appropriate Agencies/Cell Phone Relative time between incident and notification of first responders.		Item(s): 14	
Low: Populated area and/or monitored location, medium or high traffic volume Moderate: Remote area, not monitored, medium or high traffic volume High: Remote area, not monitored, low traffic volume	Low	Value = 1	Weight = 2%
Emergency Response Time (Based on Distance from Local Fire Department) Response time based on distance from nearest fire station. T = 0.65 +1.7 x D, where D is the distance to the nearest fire station in miles, T is in minutes.		Item(s): 6c, 8, 12, 15	
Low: Less than 10 minutes Moderate: Between 10 minutes and 20 minutes High: Greater than 20 minutes	Low	Value = 1	Weight = 2%
Emergency Vehicle Access Points Beneath the Structure Assess the ability for emergency responders to access under the bridge.		Item(s): 13	
Low: Fully accessible by local roads Moderate: Accessible over improved land High: Physical barriers to full access beneath the structure	Low	Value = 1	Weight = 2%
Water Access for Fire Suppression Ability to provide uninterrupted flow of water under the bridge.		Item(s): 9	
Low: Hydrant/pond within 100 feet of the farthest point of the structure Moderate: Hydrant/pond within 100 to 250 feet of farthest point of the structure High: Hydrant/pond greater than 250 feet from farthest point of the structure	Low	Value = 1	Weight = 2%
Drainage System at a Critical Point Assess the risk of spilled hazardous material collecting near critical portions of the bridge superstructure.			
Low: No scuppers on bridge or no drainage pipes along bridge Moderate: Closed system with pipes along bridge length or width near substructure High: Closed system with pipes along bridge width near midspan	Moderate	Value = 2	Weight = 2%
BASED ON ABOVE INPUT - OVERALL VULNERABILTY:	**Moderate (2.42)**		

Figure 5: Example of calculation of bridge Vulnerability score

SRA: Importance

Importance gauges the consequences of a bridge fire event in terms of uses of the bridge, effort to report and launch fire fighting intervention, and impact on the wider traffic network. The method of computing the Importance score is the same as the Occurrence and Vulnerability categories outlined above (score of 1=LOW, 2=MEDIUM, 3=HIGH, weightings applied to determine an overall score), but there are different categories that factor into the score. Figure 6 shows the example calculation. The following categories are applied:

- Traffic volume on the bridge (40%)
- Rehabilitation costs (20%)
- Assets under the bridge (20%)
- Purpose of the bridge and whether it is on a critical route (20%)

Importance	**NFPA 502 4.3.1 Item**		
Traffic Volume (ADT)	Item(s): 8		
Volume of traffic on the bridge.			
Low: Less than 47,000 Moderate: 47,000 to 175,000 High: Greater than 175,000	Moderate	Value = 2	Weight = 40%
Rehabilitation Cost (Deck Area/Number of Spans)	Item(s): 8		
Fire damage would likely result in a loss of span rather than the whole structure.			
Low: Less than 8,600 sf/span Moderate: Between 8,600 sf/span and 20,500 sf/span High: Greater than 20,500 sf/span	Low	Value = 1	Weight = 20%
Condition under the Bridge	Item(s): 19		
Assessment of impact to assets beneath the bridge in the event of a collapse.			
Low: No properties under the bridge Moderate: Roadway under the bridge High: Bridge or railroad under the bridge.	Moderate	Value = 2	Weight = 20%
Classification	Item(s): 19		
Assess the purpose of the bridge.			
Low: Rural Moderate: Suburban, non-emergency High: Urban or Emergency Route, hospital/fire department access, military route	Moderate	Value = 2	Weight = 20%
BASED ON ABOVE INPUT - OVERALL ASSESSMENT FOR IMPORTANCE:	**Moderate (1.80)**		

Figure 6: Example of calculation of bridge Importance score

SRA: Combining the Scores (Occurrence, Vulnerability, Importance) to Determine Overall Risk

Once the scores have been determined for Occurrence, Vulnerability and Importance, they are combined to determine the overall risk level of the bridge. There are two steps (A and B) to determining the overall risk. Figure 7 shows a summary of the process.

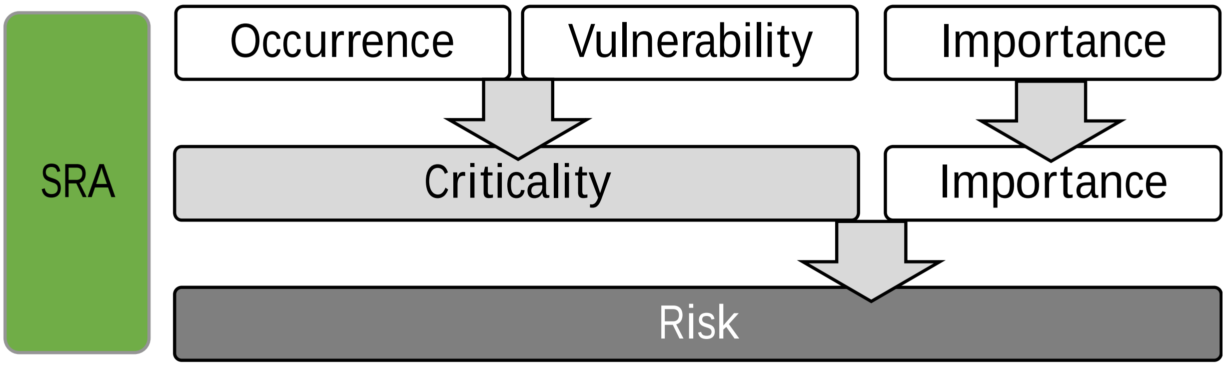

Figure 7: Hierarchy of SRA categories, leading to overall fire risk level

Step A: Criticality
Occurrence and Vulnerability risk scores (LOW, MODERATE, HIGH) are cross-referenced to give a Criticality level, defined by Table 1, where:

- CL = low criticality level
- CM = moderate criticality level
- CH = high criticality level

This step is looking at the likelihood of a fire occurring and an adverse result then being realized. This step classifies the likelihood of a fire occurring and resulting in adverse consequences.

Table 1: Matrix defining criticality levels

		Vulnerability		
		Low	Moderate	High
Occurrence	Low	CL	CL	CM
	Moderate	CL	CM	CH
	High	CM	CH	CH

From the example presented in Figure 4 (Occurrence, level is LOW) and Figure 5 (Vulnerability, level is MODERATE), the resulting criticality level would be CL (LOW).

Step B: Importance
The final risk level is defined by cross-referencing Criticality and Importance levels as per Table 2. In the example given in Figure 6, the Importance level is MODERATE. From above, Criticality is LOW (CL), and thus the overall risk level is RL. Risk levels are defined as follows:

- RL = low fire risk level. The bridge fire risk level is negligible. No further action is recommended to mitigate the risk of fire.
- RM = moderate fire risk level. There is an acceptable level of risk that a bridge fire might occur and damage the bridge serviceability, but the bridge might not collapse or cause damage that is an unacceptable level of risk to life or property. No further immediate action is recommended to mitigate the risk of fire. Ensure that adequate routine maintenance is performed during the life of the bridge, including periodic reassessments of the risk level. Ensure that proper surveillance is in place to identify and respond to incidents.

- RH = high fire risk level. The bridge has a relatively high probability of losing its load-carrying capacity, collapsing during a fire, and/or cause an unacceptable level of risk to life or property. A Detailed Risk Analysis (DRA) shall be performed to identify and mitigate the origination of the fire risk.

Table 2: Matrix defining SRA risk levels

		Importance		
		Low	Moderate	High
Criticality	Low	RL	RL	RM
	Moderate	RL	RM	RH
	High	RM	RH	RH

Summary

OCCURRENCE	VULNERABILITY	IMPORTANCE
Low	Moderate	Moderate

Criticality Matrix

		Vulnerability		
		Low	Moderate	High
Occurrence	Low	CL	CL	CM
	Moderate	CL	CM	CH
	High	CM	CH	CH

CL = Low Criticality Risk
CM = Moderate Criticality Risk
CH = High Criticality Risk

Criticality = **Low**

Risk Matrix

		Importance		
		Low	Moderate	High
Criticality	Low	RL	RL	RM
	Moderate	RL	RM	RH
	High	RM	RH	RH

RL = Low Overall Fire Risk
RM = Moderate Overall Fire Risk
RH = High Overall Fire Risk

Overall Fire Risk = **Low**

Recommendation

The bridge fire risk level is negligible. No further action is recommended to mitigate the risk of fire.

Figure 8: Example calculation of overall fire risk

Further Steps

In any fire safety risk assessment of infrastructure, where categories and quantitative scores are applied, there is an element of uncertainty. Fires tend to be rare events, which also means that there is a low level of statistical reliability of input data. For these reasons, once the SRA is completed, the designer should have a peer review of their work conducted to verify the resulting risk levels and conclusions. This can involve checking inputs, calculations, assumptions, and review of the result, relative to the overall use of the bridge, for general sensibility. For instance, if a result gave a risk of RL, but a major highway carrying gasoline tankers passed under the bridge, the risk level of RL would be questionable given the high probability of fire.

Step 3: Detailed Risk Analysis (DRA)

DRA is performed only for bridges with SRA risk level RH (HIGH) or for bridges over 1000 feet long.

Detailed Risk Analysis (DRA) may involve computer simulations, structural analysis, environmental analysis, and/or any other assessments to identify and evaluate the key characteristics that result in a HIGH overall fire risk level for the bridge.

Suggestions for mitigating risk and establishing countermeasures is the expected result from DRA analysis. Identification of the category (Occurrence, Vulnerability, Importance) most heavily contributing to the HIGH overall fire risk level from the SRA will help to direct the mitigation strategies.