Root Cause Analysis Report

Notre Dame Fire

SOLOGIC™

Problem Statement

Report Number	RCA-10-31-2019-592	**RCA Owner**	Chris Eckert
Report Date	12/4/2019	**RCA Facilitator**	Brian Hughes

Focal Point: Catastrophic damage, potential for multiple injuries/ fatalities

When

Start Date: 4/15/2019	End Date: 4/16/2019
Start Time: 6:18 PM (GMT +1)	End Time: ~ 6:00 AM (GMT +1)
Unique Timing	After not recognizing that a fire had started in the cathedral attic.

Where

Other	Notre Dame Cathedral
Other	Main attic

Actual Impact

Safety	No injuries, no fatalies	
Environmental	Elevated levels of lead and other toxins down wind of fire zone	
Cost	Estimated at $1 billion	$1,000,000,000.00
	Massive damage to Unesco World Heritage Site.	$0.00
		Actual Impact Total: $1,000,000,000.00
Frequency Note	Damage or loss to buildings of significant historical value occur occasionally.	

Potential Impact

Safety	Potential for multiple serious injuries, fatalities
	Potential for loss of many priceless artifacts, as well as the entire structure

Report Summaries

Cause and Effect Summary

DISCLAIMER – READ THIS FIRST!

SOLOGIC DID NOT INVESTIGATE THE NOTRE DAME FIRE IN ANY PROFESSIONAL CAPACITY. THIS EXAMPLE WAS COMPILED BASED SOLELY ON PUBLICALLY AVAILABLE SOURCES (MOSTLY NEWSPAPER ARTICLES). IT IS INTENDED TO BE USED AS AN EDUCATIONAL EXAMPLE FOR HOW TO BUILD A ROOT CAUSE ANALYSIS USING THE SOLOGIC METHOD AND CAUSELINK SOFTWARE.

On April 15, 2019 at about 6:20PM a fire started in the main attic of the Notre Dame cathedral in Paris, France. No one was injured or killed which is amazing due to the popularity of Notre Dame as a tourist attraction, the fact that mass was happening at the time the fire started, and also given that there were hundreds of responders. There was, however, extensive damage to the structure as well as lost or damaged historical artifacts including the 600 year old timber framing of the attic. If not for the heroic efforts of the fire crews fighting the fire, the cathedral would have been a total loss. While precise estimates to restore the building are not available, some say it could cost as much as a billion US dollars and take decades to complete.

All fires have three primary contributing causes – heat, fuel, and oxygen. When we investigate structural fires, we look at the preceding causes of each of these three main story lines. We also look at the response to the fire. Did it help, hurt, or was it essentially ineffective? We can always learn from the response.

Most people consider the ignition source to be the single most important cause of a fire. When we hear news reports about forest fires, the focus is often on what started the fire. Was it accidental, such as a campfire, exhaust pipe, or electrical spark? Was it due to negligence, such as fireworks or smoking materials? Was it purposeful – arson? Or was it due to natural causes, such as lightning? These are all important hypotheses that should be examined. Certainly, any credible fire investigation will attempt to discover the ignition source.

However, the “causes” of combustible material and oxygen are just as important as the ignition source. Have you ever tried to burn a chunk of concrete (good luck)? What happens of you put a glass over a lit candle (it goes out)? They call it “the fire triangle” for an important reason – without any one of the three, the fire cannot exist. Therefore, the stories of the combustible material and oxygen are just as important as the story of the ignition source – and perhaps even more. Why? Because oxygen and combustible material act as “constants” in the causal equation. They exist, together, over a period of time. In the case of Notre Dame, the wood of the attic and oxygen occupied the same space for centuries, waiting for an ignition source – the variable in the equation. The constants are predictable. That means they can be controlled in advance of any triggering variable. While people may argue over whether the word “cause” applies to things that simply exist, such as wood or oxygen, no one can argue their importance to the event of “fire.” FYI: At Sologic, we use the word “cause” to describe all relevant contributors to an event. We find it useful to define causes that trigger an event as “transitory” causes because they represent a point of change – a transition point – from one state to another. The ignition of a fire would therefore be labeled as a transitory cause. Causes that are required participants in the event, such as combustible material and oxygen, we label “non-transitory.” You will see these labels in the cause and effect chart that supports this root cause analysis (“T” and “N”).

Why the discussion about cause types? Because it helps us build an accurate causal model, regardless of the event we are investigating. But it is particularly relevant to the Notre Dame cathedral fire because investigators have not been able to pinpoint the transitory initiation of the fire. They did find evidence of smoking materials from workers restoring the roof. Smoking is prohibited, but they were doing it anyway. However, there was no obvious link between cigarette butts and/or matches and the

fire. Electrical ignition was also examined, yet no connection has been established. It could have been static or other natural causes – but again, there has been no definitive connection identified. What has been ruled out is arson – there is no evidence that the fire was set deliberately. While unsatisfying, we have to resign ourselves to the fact that we may never definitively know what started the fire. But that doesn't mean our investigation has run out of options.

Church caretakers were extremely concerned about fire, especially in the attic (known as "the forest"). The attic was constructed of ancient timbers, kept dry for centuries under the cathedral's lead roof. The design of the structure was perfect for a fire to spread once it got started. However there were no fire suppression systems, such as sprinklers or fire walls. A conscious decision was made that these systems would diminish the aesthetics of the historical timber structure. It may be that the fire protection plan underestimated how rapidly a fire would spread through the attic. And it may also be the case that the shear age of the structure (it had survived for hundreds of years through wars and revolutions) caused a false sense of invincibility.

The fact that these sorts of systems were considered and rejected is something we can learn from. That isn't to say that we should point the finger of blame at those that decided not to install sprinklers or fire walls. There is no question that they were doing their best to protect the structure while preserving its heritage. Hindsight bias can be cruel and unfair. However, we can examine whether that same mindset was present when making decisions about buildings of similar historical significance – and not just in Paris. Countless buildings of historical significance exist at this very moment, many of which have no fire suppression systems in place. It's not hindsight bias when we examine past decisions and alter our calculus going forward... that's called "learning."

When we think about how things might go wrong in a system, we often look at how we might detect and correct a deviation before it becomes catastrophic. Certainly those in charge at Notre Dame recognized this because they installed a very complex and robust fire alert system. This system consisted of an array of different sensing equipment that was intended to provide caretakers with the earliest possible warning of any fire, allowing them to react quickly and regain control.

This fire alert system worked exactly like it was supposed to work. A fire alarm was activated and a guard was sent to check it out. However, he was sent to the wrong location. This was because the alarm message was not correctly interpreted by the employee monitoring the system. He was very new to the job – it was his third day. Also, he had already worked an eight-hour shift but was staying on for an additional shift after his relief did not show up for work. And the system itself was difficult to interpret. The messaging provided was not intuitive. This resulted in a delay of nearly 30 minutes. In that time, the fire rapidly spread uncontrollably through the attic.

This also represents a learning opportunity. Complexity on its own makes a system less reliable. Add in the fact that the employee monitoring the system was both new and working his second eight-hour shift. We also need to consider the elevated levels of stress that anyone is subject to in a crisis of this magnitude. It is not hard to see how the fire alert system – including the humans involved – contributed to the delayed response.

On the subject of the response, it was amazing. Firefighters realized that saving the roof was a lost cause, so they pulled back to safety. However, after the spire had collapsed, they saw that the fire was spreading to the two cathedral towers. Heavy bells hung in the north tower – if it burned and they fell, they could do an immense amount of damage. And, if the towers themselves collapsed, they could potentially bring the entire building down. A team of firefighters fought their way up to the south tower. This position allowed them to put water on the north tower, bringing the fire there under control. However, they put themselves at enormous risk to accomplish this feat.

Participating in the response was approximately one hundred people who formed a "bucket brigade" to remove priceless items from the church. While there were undoubtedly losses of priceless historical items, many items were saved due to this effort.

The cathedral roof was made from lead. This lead melted and ran down into the flames. Paris lead levels are generally five times the indoor legal limit, largely due to runoff from intact lead rooves. At this time, it is uncertain whether the lead from the burning roof caused elevated levels in the areas surrounding the church.

Once we consider the design and the materials of the roof, the absence of fire suppression, and the difficulties introduced by the

fire alert system, we can easily understand how an event of this magnitude could occur – even if we may never know the source of ignition. But when we consider all the contributors to the fire, we can see that the ignition source itself may be the least-interesting aspect. This is because all the other causes of the fire were present together for a considerable period of time. You could argue that, given enough time, the cathedral was always going to burn. It was just waiting for something to initiate the fire.

This lesson is relevant to every adverse event we investigate. Most of the causes of your next accident, outage, or quality event exist at this very moment waiting – like Notre Dame – for a triggering event to set them into motion. When we investigate past events, they offer a window into our future. If we focus only on the triggering causes (and often the people associated with them), we miss the important "causal constants" that give us opportunities to design more resilient systems that reduce risk.

Note: All solutions listed were provided by Sologic. No specific set of solution recomendations have been published as of December, 2019. Note that these solutions are based on the causes identified in the chart, however Sologic is not qualified to assess their feasibility or effectiveness.

Solutions

SO-0001	**Solution**	From Sologic: Rebuild using fireproof material.
	Cause(s)	Structures were largely made of wood
	Note	Wood burns because it can burn. Replace the roof structure with steel beams. Not only will it be stronger and last longer, but it will also be fire-proof.
	Assigned	**Criteria** Passed
	Due	**Status** Selected
		Cost
	Priority	
SO-0002	**Solution**	From Sologic: Redesign the alarm interface so that messages are impossible to misinterpret
	Cause(s)	Alarm system was not intuitive, difficult to interpret/understand
	Note	The alarm system accurately detected smoke. However, the way in which this information was relayed to the employee monitoring the system was confusing and unclear. The user interface needs to be redesigned to dramatically improve the ability for someone monitoring the system to accurately interpret the alarms.
	Assigned	**Criteria** Passed
	Due	**Status** Selected
		Cost
	Priority	
SO-0003	**Solution**	From Sologic: Only assign experienced, trained, and certified employees to monitor fire alarms.
	Cause(s)	Employee monitoring the alarm system was inexperienced (3 days)
	Note	Everyone starts somewhere. But those monitoring critical alarm systems should have experience or be closely supervised. Conduct training, drills, and audits to help quickly move new employees along the learning curve.
	Assigned	**Criteria** Passed
	Due	**Status** Selected
		Cost
	Priority	
SO-0004	**Solution**	From Sologic: Alarm system to automatically contact fire department. Only the FD can shut off the alarm.

	Cause(s)	Fire department was not automatically alerted		
	Note	The fire department was not contacted until 30 minutes after the fire started. The alarm system should contact the fire department automatically. The fire department should be in charge of deactivating the alarm. That way, they can be sure that everything is okay. And if there is a problem, they are on site to handle it.		
	Assigned		**Criteria**	Passed
	Due		**Status**	Selected
			Cost	
	Priority			
SO-0005	**Solution**	From Sologic: Limit monitoring time to ensure employee alertness.		
	Cause(s)	Employee monitoring the alarm system working 2nd shift in a row		
	Note	No person is immune to boredom and tediousness. Monitoring alarms that likely never activate is mind-numbing work. Suggest limiting the hours any one employee is tasked with monitoring alarms.		
	Assigned		**Criteria**	Passed
	Due		**Status**	Selected
			Cost	
	Priority			
SO-0006	**Solution**	From Sologic: Change risk assessment process.		
	Cause(s)	Fire protection plan underestimated speed a fire would spread		
	Note	There was a systemic blindspot in the risk assessment regarding how quickly a fire would spread, the likelihood that a fire would start, how quickly a fire could be brought under control, etc. If this same		
	Assigned		**Criteria**	Not Checked
	Due		**Status**	Selected
			Cost	
	Priority			
SO-0007	**Solution**	From Sologic: Install comprehensive fire suppression system.		
	Cause(s)	No fire protection systems installed (sprinklers, fire walls)		
	Note	The decision to preserve the visual aesthetic without sprinklers, fire barriers, etc. left the cathedral at risk. Had a robust fire suppression system been in place, it likely could have reacted much faster to the fire, extinguishing it or at least keeping it from escalating until help could arrive.		
	Assigned		**Criteria**	Passed
	Due		**Status**	Selected
			Cost	

	Priority			
SO-0008	**Solution**	From Sologic: Strictly enforce ban on smoking on the premises.		
	Cause(s)	Smoking materials (cigarettes) from workers?		
	Note	The investigation so far has determined that the fire was not started by smoking materials. However, there is a ban against smoking by contractors because it is a potential ignition source. The ban needs to be strictly enforced.		
	Assigned		**Criteria**	Passed
	Due		**Status**	Selected
			Cost	
	Priority			
SO-0009	**Solution**	From Sologic: Ensure work that could trigger a fire (welding, electrical, soldering, etc) are set up with multiple levels of fire protection.		
	Cause(s)	Construction activities ignited the fire?		
	Note	Examine all hot work with respect to the risk of igniting a fire. Does the work have to be completed on site, or can it be done prior to shipping? If it has to be completed on site, does it have to be done near centuries-old timber, or can it be done in an area that is less exposed to combustible material? Set up hot work areas with multiple levels of fire prevention. Anticipate and capture or block sparks. Protect exposed wooden beams. Clean up all debris that could catch fire (wood chips, oil/cleaners, sawdust, etc.). Ensure a second employee with access to a fire extinguisher is nearby. And be sure to look for alternatives to hot work - can the work be completed in a different way?		
	Assigned		**Criteria**	Passed
	Due		**Status**	Selected
			Cost	
	Priority			
SO-0010	**Solution**	From Sologic: Conduct comprehensive electrical risk assessment - redesign any electrical systems that contribute significant safety risks.		
	Cause(s)	Electrical?		
	Note	Conduct a site-wide audit of existing electrical infrastructure. Include fire safety as an audit criteria.		
	Assigned		**Criteria**	Not Checked
	Due		**Status**	Selected
			Cost	
	Priority			

Evidence

EV-0001	Article: "Notre-Dame came far closer to collapsing than people knew. This is how it was saved." New York Times, July 18, 2019
EV-0002	Article: "Timeline: How the Notre Dame Fire Unfolded" Reuters, April 15, 2019
EV-0005	"Notre Dame fire could have been started by a cigarette or an electrical fault, prosecutors say" By Saskya Vandoorne, Antoine Crouin and Bianca Britton, CNN Wed June 26, 2019
EV-0003	Wikipedia Entry
EV-0004	Preliminary Investigation

Notre Dame Fire

Timezone: Europe/Paris

4/14/1163

Work Begins on the Cathedral

4/14/1345

Cathedral Completed

4/15/2019 06:18 PM

Red warning light flashed on smoke alarm monitoring panel "Feu" (fire)!

A security employee was monitoring the smoke alarm panel when the warning light began flashing. He then radioed a guard to check it out. He was located in the Presbytery, a smaller building located south of the main Cathedral.

4/15/2019 06:22 PM

Church guard sent to check on alarm source.

The employee monitoring the smoke alarm system radioed a church guard. He was in the main cathedral monitoring mass, including several hundred people. He was told to check the Sacristy - a building located to the south of the main Cathedral. There was no fire present in the Sacristy. He reported his findings back to the control room.

4/15/2019 06:28 PM

The Security Employee called the Manager to report the "false" alarm.

The Security Employee called the Manager to report the alarm, but was unable to reach him. He left a message.

4/15/2019 06:43 PM

The Manager called back: "Run to the main attic!!"

The Manager called back upon receiving the message. After some time, he realized that the team onsite had possibly made a mistake. He ordered the guard to "run to the main attic!"

4/15/2019 06:48 PM

Fire burning out of control in main attic.

By the time the guard climbed the 300 steps to the attic, the fire was completely out of control in the rafters, known as "the forest" due to its massive timbers. Only then was the fire department called.

4/15/2019 06:51 PM

Fire Fighters were Called

The alarm system does not automatically summon the fire brigade.

4/15/2019 07:00 PM

Fire Fighters Arrive on Site

More than 400 fire fighters were engaged in fighting the fire. 100 people formed a human chain to move precious objects to safety.

4/15/2019 07:40 PM

Fire Spreads to North Tower

The fire spread to the wooden framework in the north tower, which supports 8 large bells.

4/15/2019 07:50 PM

Spire Collapses

When the spire collapsed, it sent a powerful draft/fireball through the attic structure, slamming doors and causing firefighters to retreat.

4/15/2019 08:20 PM

Firefighters Abandon Trying to Save the Roof

Firefighters realized the roof was lost. So they focused efforts on saving the towers from collapsing.

4/15/2019 09:45 PM

Fire is Brought Under Control

4/14/1163 4/14/1345 6:19 PM 6:28 PM 6:37 PM 6:46 PM 6:55 PM 7 PM 7:04 PM 7:13 PM 7:22 PM 7:31 PM 7:40 PM 7:49 PM 7:58 PM 8 PM 8:07 PM 8:16 PM 8:25 PM 8:34 PM 8:43 PM 8:52 PM 9 PM 9:01 PM 9:10 PM 9:19 PM 9:28 PM 9:37 PM 9:46 PM

Chart Key
- Transitory
- Non-Transitory
- Transitory Omission
- Non-Transitory Omission
- Undefined
- Chart Quality Alert
- Focal Point
- Evidence
- Notes
- Solutions
- Tasks

Catastrophic damage, potential for multiple injuries/ fatalities

- Near total collapse of the building
  - Extensive damage to the building
    - The roof, steeple, north tower, and other structured burned
      - Combustible Material: Wood building materials (beams, framing, etc)
        - Structures were largely made of wood — END
          - Terminated because: Other causal paths more productive
        - Age of the wood - much of it was several hundred years old — END
          - Terminated because: Other causal paths more productive
      - Oxygen: Ambient — END
        - Terminated because: Other causal paths more productive
      - Ignition source: Unknown
        - OR
          - Smoking materials (cigarettes) from workers? — ?
          - Electrical? — ?
          - Static or other natural causes? — ?
          - Construction activities ignited the fire? — ?
          - Fire set deliberately? — END
            - Terminated because: Disproved
      - Duration of the fire allowed it to spread
        - Structural Design - allowed fire to quickly spread — END
          - Terminated because: Other causal paths more productive
        - No fire protection systems installed (sprinklers, fire walls)
          - Fire protection plan underestimated speed a fire would spread — END
            - Terminated because: Systemic: Further investigation
          - Desire to preserve historical elements — END
            - Terminated because: Other causal paths more productive
        - Delayed fire response
          - Fire Alarm activated — END
            - Terminated because: Desired State
          - Guard sent to investigate alarm, but sent to the wrong location
            - Location of alarm activation misinterpreted
              - Alarm system was not intuitive, difficult to interpret/understand — END
                - Terminated because: Systemic: Further investigation
              - Employee monitoring the alarm system was inexperienced (3 days) — END
                - Terminated because: Other causal paths more productive
              - Employee monitoring the alarm system working 2nd shift in a row
                - Relief employee did not show up for work — END
                  - Terminated because: Other causal paths more productive
          - Fire department was not automatically alerted — ?
    - Prevented by "heroic" efforts by the fire fighters — END
      - Terminated because: Should be a movie - nice work!
  - Many people in or near the Cathedral at the time of the event
    - Visitors to the church — END
      - Terminated because: Other causal paths more productive
    - Employees and church members — END
      - Terminated because: Other causal paths more productive
    - Firefighters and other responders — END
      - Terminated because: Other causal paths more productive