HUMAN/ORGANIZATIONAL PITFALLS AND LESSONS

THE HALL OF FAME OR THE HALL OF SHAME?

Steve Nowaczewski, Nova Northstar LLC

Battelle/Sandia Workshop

Reliability & Risk Management of SSSVs for UGS Applications

Denver, CO; March 4-5, 2020

Let's ponder human and organizational issues that lead to disasters.

On November 5, 2015, Samarco's Fundao/Santorem tailings dam failed. It was the worst tailings dam failure in history.

The failure of part of the earthen dam allowed the contents behind the dam to completely evacuate, sending a wall of iron mine tailings laden mud rushing downstream, with an ultimate run-out of >600 km all the way to the sea.

The town of Bento Rodrigues was wiped out – at least 17 killed. Residents were warned by word of mouth and not by company actions. The company had no warning system in place. Prior to the failure, company reps repeatedly assured village residents that they were safe.

The release volume is estimated at up to 60 million cubic meters. Rio Doce was destroyed and may take '~100 years' to recover

The government is suing for damages estimated at $5.2 billion US

This was a man-made disaster. Man mined iron ore. Man made a dam to hold mine tailings. The organization was responsible for dam integrity. One of Brazil's leading experts inspected the dam in September 2014, noted cracking, believed it could be incipient failure, and recommended increased monitoring and installation of a buttress to reinforce the dam. Samarco disputes the engineer's account, saying they followed the recommendations and were not warned of imminent failure, and they claim they were 'strengthening' the dam when it failed, but even when aware of the expert's report, did not alert the downstream public to any increased risk.

Liquefaction is a major cause of earth dam failure. Samarco referred to minor (2-2.6 richter scale) tremors when discussing failure, which, they said was completely unforeseen. "The dam was stable…until the date of the seismic occurrences, whose contribution to the event should be duly considered" says the company.

The dam expert: "What I think was lacking was a belief in the worst-case scenario, and the worst-case scenario was viable."
Samarco said the expert was aware of what was being done to the dam, never protested, and is "trying to avoid blame". The expert says Samarco departed from his design after 2012.

HUMAN AND ORGANIZATIONAL FACTORS

SPE Technical Report March 2014:
The Human Factor: Process Safety and Culture

Ten human factors risks to be addressed:

- Leadership and Culture
- Perception of Risk and Decision-Making
- Communication of Risk
- Human Factors in Design
- Individual and Team Capacity
  - Training, Competency
  - Operational Control of Work
  - Management of Change
  - Assurance
- Collaborative and Distributed Team Working
- Commercial and Contractual Environment
- Workload Transition
- Assurance of Safety-Critical Human Activities
- Investigating and Learning from Incidents

Risk of Major Accidents: Causal Factors and Improvement Measures Related to Well Control in the Petroleum Industry SPE #163775, Lootz, et.al., Petroleum Safety Authority Norway

	Failure Causes (Percent)		Measures for
Barrier	Triggering	Underlying	Improvement
Human	15	14	3
Organizational	17	78	79
Technical	68	8	18

Improvement measures

Improve procedures/documentation 19%

Improve control/check/verification 12%

Increased competency/training 10%

Increased work practice 9%

Improved technical design 9%

It is clear from this incident that there are organizational barrier weaknesses – human factors compiled into organizational behaviors, that allowed this catastrophe to occur.

The Society of Petroleum Engineers recently published a technical report on human factors at work in process safety and culture. You also can see from the SPE paper from Lootz et al and the Petroleum Safety Authority of Norway that major accidents result from underlying causes that are predominantly human and organizational, and we have great opportunities for improvement of procedures, competency, work practices, and so forth.

Our role is to acknowledge a need to improve resilience of our human and organizational barriers and protect against barrier decay; let's focus specifically on aspects of:
Leadership and Culture
Risk assessment and communication
People, quality, capability (expressed in many ways – stds, procedures, training, operational control, group work environment…)
Management of change
Review and assurance

JANUARY 25, 2019 FAILURE – CORREGO DO FEIJAO

- 270 dead
  - Water accumulation
  - Failure of P/M drainage system
  - Failure in drainage monitoring system
  - Liquefaction, catastrophic flow
- Inspection report Sept 2018 - 4 mos. prior
  - Faulty water drainage systems
  - Faulty monitoring systems
  - Yet certified the dam as safe
    - ?conflict of interest? inspection company, mine owner had other business relationships, creating pressure on certification sign-off

- Inspection should not have certified the dam safety, due to the faults and the potential consequences;
- owner should have been aware of the risk of failure and risk of monitoring weakness

Well, if the 2015 event wasn't enough, the same parent company experienced another catastrophic event in 2019. In this event, more people died.

The 2019 incident very likely was preventable. The operator had knowledge of issues. Of course, many issues might have started much earlier – from design and construction to ongoing integrity management.

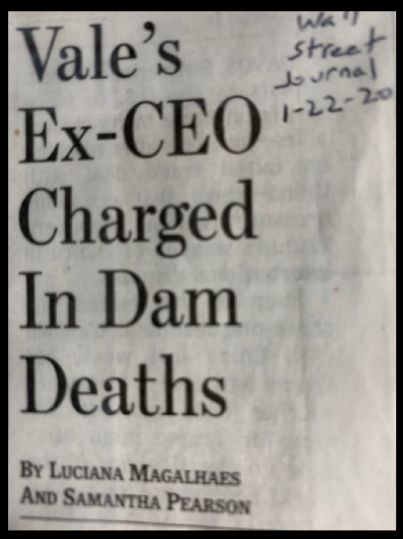
JANUARY 25, 2019 FAILURE – HUMAN-ORGANIZATIONAL ISSUES

RNAL.

Monday, February 24, 2020 | B3

BUSINESS NEWS

Report Faults Culture at Vale


Vale's Ex-CEO Charged In Dam Deaths

Wall Street Journal 1-22-20

By Luciana Magalhaes And Samantha Pearson

The company responsible for the dam suffers more than just the immediate effects – there is reputational damage, and senior leaders are implicated – they are not able to escape scrutiny for their actions in integrity management within the scope of their social license to operate.

The graffiti says, essentially, Vale is a recidivist murderer. Note the recent report, commissioned by the company itself, cites culture as a cause of the disaster.

JANUARY 25, 2019 FAILURE – HUMAN-ORGANIZATIONAL ISSUES

RESPONSIBILITY, STANDARDS, AWARENESS OF RISK

- Owner says they were following up on inspection report recommendations and that the follow-ups were 'routine'…
  - …but if the report did not send the proper alarms and warnings to the owner, then follow-ups may have appeared routine but acceptance of the inspection report concealed the full measure of risk
  - 130 monitoring instruments, analyzed 'periodically'
  - Owner asserts that:
    - inspection company said dam was stable
      - shifting responsibility…obviously the dam was not stable; ultimately owner is responsible to prevent failure, not the inspection company…
    - dam met global safety standards and exceeded Brazil's industry standard
      - (this is not saying much and represents a lack of awareness, and again a lack of acceptance of responsibility by a very large, multinational, very wealthy company. Safety standards are typically reactive *(Brazil is now strengthening the standards in response to these two failures)*; an industry leader should be setting a higher standard, shouldn't they? Running for cover under standards is not enough)
  - Owner did not admit it even had such dams after the 2015 incident, all the way through to 2017…**why?**

Let's go through several slides where we dissect the reasons for these dam tragedies.

First, let's concentrate on the issues of responsibility, standards, and awareness of risk…

JANUARY 2019 FAILURE – HUMAN-ORGANIZATIONAL ISSUES

AWARENESS/KNOWLEDGE OF BARRIERS, FUNCTIONAL INTEGRATION, MONITORING

- Yet the report revealed issues…
  - …damaged drainage system – collapsed and/or clogged drainage conduits; in lower levels of the dam no drainage system at all
    - Weakness in inspection and remediation to keep a key barrier intact
    - Design weakness, and subsequent awareness of such, thus weakness in efforts to do anything to make up for it
    - **Why?** False assumption that such barrier inadequacy was not critical? Complacency? Cost control a priority over safety?
  - Siphons not installed everywhere to suppress air entry, some installed incorrectly
    - Weakness in design and construction
    - Weakness in awareness of siphons as a critical element supporting barrier functionality
    - **Why?** Same questions as above, but also with an element of time removing awareness of siphons as even a critical design element (who would know, who was supposed to know, institutional/experiential knowledge?)
  - Problems detected in previous inspection remained unresolved…
    - Weakness in preventive and corrective maintenance management
    - **Why?** Same questions as above…

And let's discuss awareness of the role of barriers, their function in integrated systems – which leads to better understanding of threat interaction and potential for escalating and/or cascading risk.

JANUARY 2019 FAILURE – HUMAN-ORGANIZATIONAL ISSUES

SAFETY FACTORS, OPERATING WINDOWS, THREAT INTERACTION, SENSE OF URGENCY

- Yet the report revealed issues…
  - …factor of safety analysis revealed dam could fail if tailings were undrained (water-laden)
    - Weakness in establishing operating windows and safety factors to account for worst case scenarios
    - Weakness in perception of risk from all sources, including interacting threats (seismic activity, dam level vs. capacity, and dam water content vs. expectation, plus state and condition of detection, prevention, and mitigation systems)
    - **Why?**
  - Despite Fundao dam failure (in which owner was a partner) and interacting threats of undrained (water-laden) tailings and seismic tremors, the Brumadinho dam had no seismic monitors. Company was "planning to install one"
    - Weakness in learning/adapting lessons learned from other failures to ongoing operations
    - Weakness in sense of urgency
    - **Why?**
  - Inspection report consequence analysis showed that dam failure could be catastrophic…what was company doing to minimize consequences in event of failure?
    - Weakness in imagining and planning for worst case failure?...in addressing interacting threats?
    - Weakness in sense of urgency when failure could (and did) have catastrophic consequences
    - **Why?**

Safety factors and operating windows give us parameters against which to evaluate performance metrics and focus us on monitoring and maintenance – in particular enabling a sense of urgency since we have sometimes poor understanding of how threat interactions can escalate and cascade.

2016 GTI REPORT – "APPROACHES FOR PREVENTING CATASTROPHIC EVENTS" -

DOT CONTRACT DTPH5615T00001L, PROJECT NUMBER 638, GTI PROJECT NUMBER 21878

- Investigation of major events reveals human-organizational causal factors
- **"Concealment"** *of information a major underlying issue in industrial disasters*
  - ***Normalization of deviance*** Defects often disguised, hidden or ignored, minimized, or not sought
  - ***Limited Vision/Limited Effort*** Low expectation for anything beyond the norm, did not seek the unexpected
  - ***Poor information management***, sharing and integration, low motivation to do so – no system for managing knowledge about risks within the industry (through accumulation, systematization, and communication)
  - ***Poor knowledge management***, no or low motivation to seek all there is to know – prior events in the world may exist, but effort to find and adapt lessons learned lacking; worse, institutional forgetfulness of events and lessons, complacency due to recurring events (normalization) or in the absence of recurring events
  - ***Inadequate, non-comprehensive, poor-quality/poor analysis inspections and monitoring*** – low frequency event may have preceding early warning signals
- ***Opposites of "conceal": "reveal", "disclose"***

Now on to pipeline facilities and major events…an excellent research report from GTI in 2016 summarized reasons for catastrophic events and new ways of thinking about integrity management. Common to many disasters, concealment and lack of awareness or acceptance of the presence of threats, along with organizational weaknesses, lead to failure.

2016 GTI REPORT – *"APPROACHES FOR PREVENTING CATASTROPHIC EVENTS"* -

DOT CONTRACT DTPH5615T00001L, PROJECT NUMBER 638, GTI PROJECT NUMBER 21878

- **Problem areas include:**
  - Humans predisposed to self-forgiveness, self-deception, and hindsight bias – recent events considered more predictable than they were before they took place, while low-frequency events are "black swans", thus impossible, uncontrollable, (inconvenient?)
  - Safety culture – need focus on process safety metrics, leading and lagging indicators
  - Hiding behind regs - minimal compliance not enough; compliant not same as "safe"
  - Threat interaction and complexity understanding is hard; requires effort / imagination
  - Lack of lessons learned, internal transparency, audits; industry sharing / transparency
  - Lack of resources dedicated to planning for catastrophe – productivity incentivized instead
  - Lack of system understanding, inadequacies of process, training, discipline
  - Competency issues – initial, building, ongoing skills and qualifications, legacy knowledge transfer of IM skills, institutional knowledge, experience, wisdom, judgment
  - Sense of vulnerability – regulations not enough to "make safe", infrastructure ages, complexity increases, complacency may set in and work adversely w/ competency issues

The GTI report noted many problem areas…

2016 GTI REPORT – *"APPROACHES FOR PREVENTING CATASTROPHIC EVENTS"* -

DOT CONTRACT DTPH5615T00001L, PROJECT NUMBER 638, GTI PROJECT NUMBER 21878

- Barrier condition/functionality poorly attended to – esp. at senior levels in the org – can result in poor resource attention to barrier monitoring
- Barrier interaction, interdependency not well understood at senior levels in the org; miss early warning signs
- Complacency, casual compliance can result from insufficient / inadequate metrics on barrier purpose/function, interaction, interdependency, and condition and function monitoring, and these can compound

Improvement Path – Metrics, Analysis, Understanding and Communication:
Promote performance improvement w/ consistent, rational metrics, incl. leading indicators (such as where a barrier didn't fail but didn't perform as expected)

Metrics-based performance monitoring promotes dialogue and analysis, reduces complacency, can increase reliability, and reduce risk of major events

Making the points we've already discussed with the dam failures, GTI notes that poor attention and understanding of barriers, their condition and functionality, also give life to complacency and can promote a culture of casual compliance, all of which can lead to threat interactions that are not sensed in the organization. GTI recommends improvement by focusing on performance metrics and performance management, including focus on leading indicators.

2016 GTI REPORT – "APPROACHES FOR PREVENTING CATASTROPHIC EVENTS" -

DOT CONTRACT DTPH5615T00001L, PROJECT NUMBER 638, GTI PROJECT NUMBER 21878

- Catastrophic events = low-probability, high-consequence events.
  - estimates of likelihood unreliable
  - joint probability of more than one interacting event very difficult; interacting threats can result in greater impact severity than independently occurring single threats
  - poor understanding of how failures propagate/amplify within/across a complex systems (and "systems of systems")
  - probability distributions w/ asymmetrical long tails - difficult to characterize… frequency is so low that there may be little historical data
- Lack of data, and familiarity, can lead to underestimation of low-probability, high-consequence events - exacerbated for power law, "heavy tail" distributions
- Bayesian networks help resolve such issues, integrating multiple uncertain inputs, producing meaningful posterior distributions.
  - useful for informing decisions when existing information is vague or uncertain
  - prior probabilities can be updated with new information
- Bayesian decision theory allows incorporation of subjective probability judgments into assessments

GTI recommends, long-term, adoption of probabilistic methods, such as Bayesian Networks (BN), which can work w/sparse input data and provide reasonable initial estimates of likelihood, then be updated as data become available. Bayesian networks can synthesize disparate models (engineering, behavioral, historic data, anecdote), into a coherent model providing meaningful insights

Hybrid BN are a tool for coherent, forward/backward reasoning; BN promotes progress towards robust system of systems approach to risk management by adapting decision networks for risk analysis – add or delete nodes as knowledge of the system interactions increases.

But consider Apostolakis "How useful is Quantitative Risk Assessment": formal peer review is an essential part of the QRA process; decisions are "risk informed" as opposed to "risk based" - factors other than engineering risk analysis can impact decisions (such as values-based criteria). QRA may struggle with: Human errors, Software failures, Safety culture, Design and manufacturing errors

2016 GTI REPORT – "APPROACHES FOR PREVENTING CATASTROPHIC EVENTS" -

DOT CONTRACT DTPH5615T00001L, PROJECT NUMBER 638, GTI PROJECT NUMBER 21878

- Defense in depth emphasize barrier redundancy (5 levels below) – system works on when a component fails
- Observability in depth monitor safety barrier condition, sense and act on hazardous conditions, understand potential accident sequences

Table 5. Levels of Defense, Objective, and Essential Means

Level of Defense in Depth	Objective	Essential Means
Level 1	Prevent abnormal operation and failures	Conservative design and high quality in construction and operation
Level 2	Control abnormal operations and detect failures	Control, limiting, and protection systems and other surveillance features
Level 3	Control accidents within design basis	Engineered safety features and accident prevention
Level 4	Control severe system conditions, including prevention of accident progression and mitigation of the consequences of severe accidents	Complementary measures and accident management
Level 5	Mitigation of significant consequences and releases	Off-site emergency response

Improvement Path:
Defense in depth + observability in depth

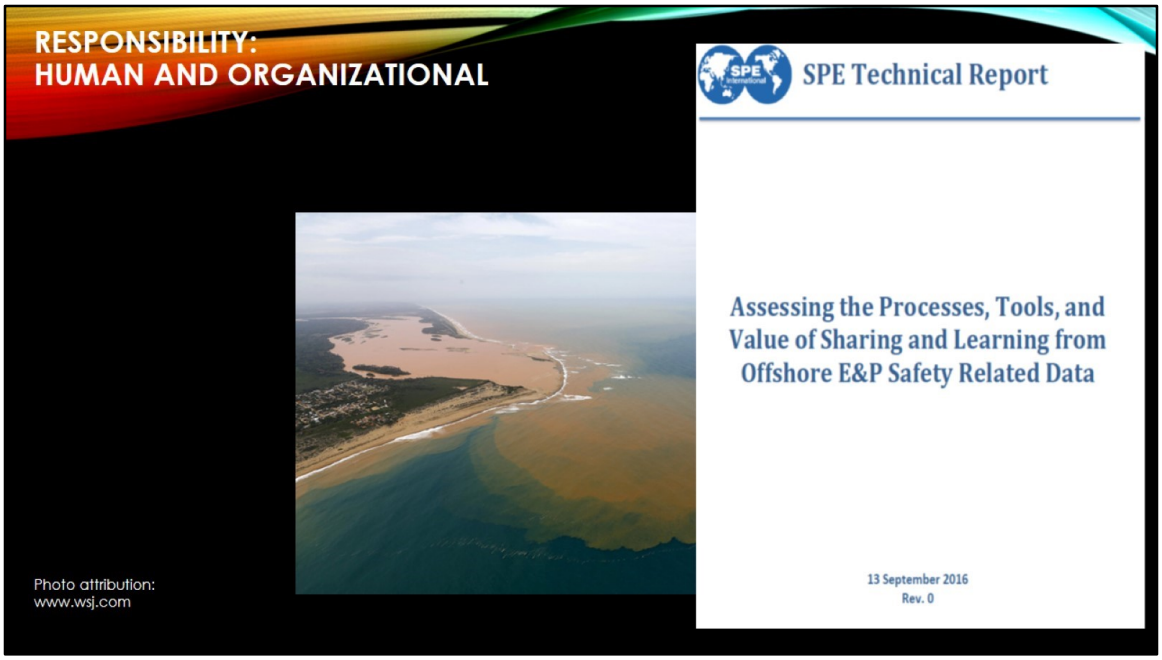
Redundancy: multiple layers, engineering and human-organizational barriers

Robustness: barriers, incl. training to understand barrier functionality and importance; incl. design / rehabilitative robustness w/ safety factors to operating windows

Robustness: barrier monitoring, making sense of the monitoring information

Robustness: understanding and action:
- response to signals of functionality loss or weakness of barriers,
- relationship of barriers and possible cascading /interacting failures leading to major accidents

Finally, GTI recommended a focus on defense in depth, redundancy and robustness, within reason and the need and organization's ability to manage the redundancy and robustness.



As we reflect on other major disasters, I encourage each of you to focus on looking at your own behaviors in terms of risk assessment and risk communication, and then focus on your organization and work to strengthen all barriers to potential events, but with special attention on the human and organizational barriers. Then, let's collaborate, innovate, and increase our integrity and responsibility!

To promote learning and safety, I suggest advancing storage industry efforts on safety and reliability data. There are good examples of this, one embodied in another SPE Technical Report from the Offshore industry. I encourage you to look over that report and find ways to organize a similar effort for gas storage.

Battelle/Sandia UGS Well Risk Model

The quantitative and practical approach to evaluate UGS well risks and applicability of SSSVs

Slawek Winecki
Battelle

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Outline

The goal of this part of our presentation is to describe the quantitative risk model used by Battelle/Sandia team for evaluation of SSSVs in UGS wells.

- What kind of model do we want?
- Probabilistic failure models, and why can't we use them here?
- API 581 approach
- The JITF 2017 model
- Battelle/Sandia additions
- LOFI & COFI estimates
- Bowtie diagrams
- Types of wells used in our simulations
- Workover risks in the real-world

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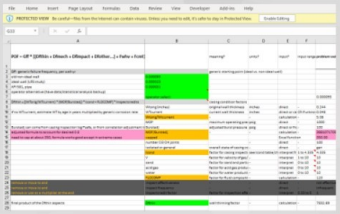
What kind of risk model do we want?

Battelle/Sandia team wanted to develop a risk model meeting the following criteria:

- Quantitative – not just ranking of risks but actual estimations of likelihood and consequence for loss of control events using understandable mathematical expressions
- Based on current models developed for UGS industry – a model which is already known and based on the API 581 principle
- Practical and simple – model which is as simple as possible, implementable as an Excel spreadsheet
- Flexible – UGS operators should be able to modify the model to their specific situations. The model should be adaptable to SSSV and T&P use
- Effective discussion platform – a set of few equations and several underlying numerical assumptions that can be discussed and improved in the constructive way.

$$LOFI_{workover} = Frequency_{workovers} \times Likelihood\ of\ failure_{workover} \times Credit_{mgm\text{-}workover}$$



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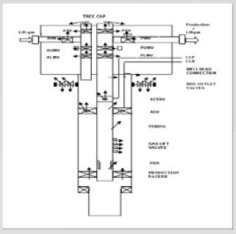
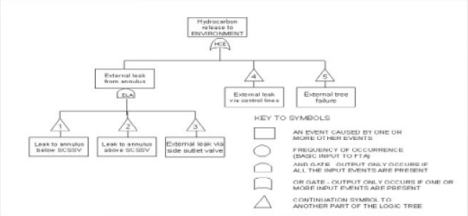
Probabilistic failure models





The probabilistic models are commonly used for risk analysis:

- Established and well-known method to predict well failure probabilities
- Costs of failure are usually not included in this analysis
- Excellent method IF all required failure rates are available
- We suggest building reliability data sets over time as we found that the state of past reliability information begs many questions and could be improved. Collecting such information serves to hone and improve quantitative-probabilistic risk analysis models

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API 581 approach

There are multiple reasons the API 581 approach can be used:

- American Petroleum Institute (API) 581 Risk-Based Inspection Technology recommended practice can be applied to pressurized systems – like UGS
- PHMSA has signaled desire for more quantitative, probabilistic risk models for natural gas integrity management systems (see Pipeline Risk Modeling - Overview of Methods and Tools for Improved Implementation, Pipeline and Hazardous Materials Safety Administration May 9, 2018 (Draft 1))
- API-AGA-INGAA Joint Industry Task Force (JITF) Risk Management work group adapted API 581 methods to model risks in UGS wells; some UGS operators are using this approach or company-adapted versions of it
- Both likelihood and consequence of failure are included; permits cost-benefit analysis; does not include workover risk
- Battelle/Sandia team believes this approach is an elegant and practical method to analyze risks and guide design, safety, and management decisions.

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Battelle/Sandia model

The Battelle/Sandia model adopted most parts of the JITF model with a few additions:

- SSSV workover risks were added to the LOFI estimates
- COFI estimates were calculated with and without SSSV
- Several common UGS well construction styles and several reservoir/population density locations were considered within the model
- Risks and benefits of SSSV installation were evaluated
- An equivalent model for T&P application in UGS wells is under development.

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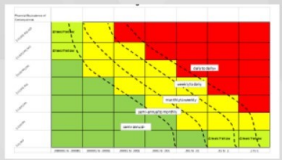
API 581 approach

Likelihood of Failure Index (LOFI) estimation [likelihood/year]

Consequence of Failure Index (COFI) estimation [$/failure]

Details of LOFI and COFI estimates provide valuable insights about system design and risk management

Risk matrix



Annualized risk (LOFI×COFI) estimation [$/year]

The API 581 approach provides:

- Realistic and quantitative method to estimate LOFI and COFI values
- Can be applied with limited failure rate data because it starts with an assumed generic failure frequency
- Effective way to guide risk decisions because it provides annualized risks this cost/benefits can be evaluated in a common way
- Frequency of inspection, testing and monitoring can be set against the risk matrix in a somewhat quantitative way
- ISO 16530 (Well integrity) contains similar risk matrix and maintenance frequency diagram

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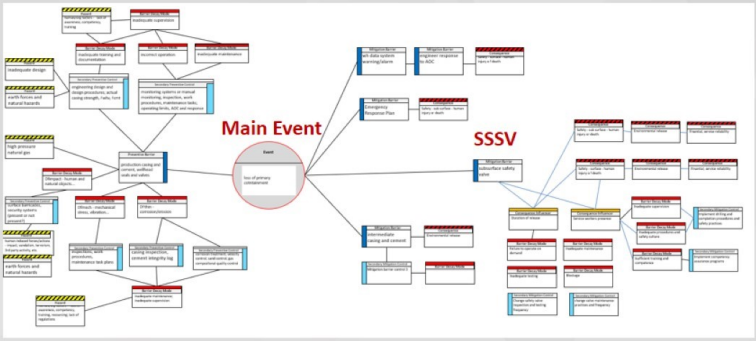
Bowtie diagram



Hazards and preventive barriers

Consequences and mitigation barriers

The bowtie is a good way to visualize:

- Hazards and barriers around the type of event that is being analyzed
- Degradation mechanisms attacking barriers, commonly referred to as 'threats'
- Procedures, tests, and inspections to manage barrier condition and effectiveness.

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JITF model LOFI estimate – what is included

$$LOFI = Gff \times [(Df_{thin} + Df_{mech} + Df_{impact}) + F_{whv} + F_{cmt}] \times Credit_{mgm}$$

Gff - general failure frequency – from industry data/experience

Df_{thin} - wall thinning –MOP, wall thickness, corrosion rate, age and/or years since last inspection, burst strength, wall condition

Df_{mech} - mechanical damage – vibration, previous failures, earth forces, physical barriers, well work stresses

Df_{impact} - impact damage – vehicular impact, falling objects, preventive controls

F_{whv} - wellhead failure factor – design (API, non-API), condition, pressure rating, testing

F_{cmt} - cement sheath factor – cement condition, annular flow factor, cement functionality factor

$Credit_{mgm}$ - management system credit – API 1171 implementation, test completion factor, maturity of inspection program

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JITF model COFI estimate – what is included

$$COFI=(COFI_{safety\text{-}surface}+COFI_{safety\text{-}subsurface}+COFI_{environmental}+COFI_{financial})\times Credit_{mitig}$$

$COFI_{safety\text{-}surface}$ – safety consequences of surface gas release with fire, heat impact radius, population density in the critical heat impact radius, PHMSA accident safety pipeline effect statistics

$COFI_{safety\text{-}sub\ surface}$ – safety consequences of sub surface gas release with no fire, volume of released gas, population density within 9-mile radius, safety consequence distribution

$COFI_{environmental}$ – estimated consequences of gas release to air, water, soil, and associated environmental degradation

$COFI_{finantial}$ – estimated financial costs due to emergency response, product loss, repairs, public reputation, other

$Credit_{mitig}$ – credit for mitigation system(s) and their reliability. The mitigation system must be technical/ hardware, not human or procedural

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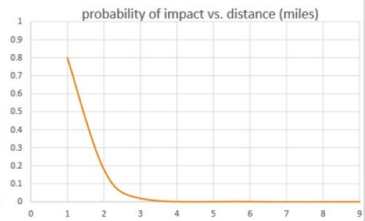
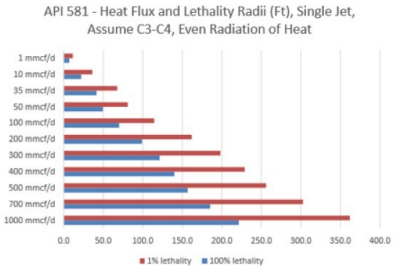
Consequence failure analysis with respect to safety

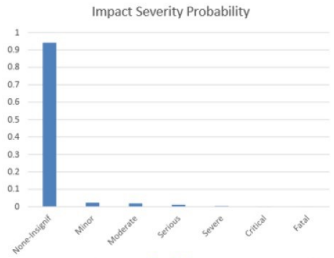
Critical aspects for consequence scenarios:
- Maximum flow potential
- Sustained (30-day) flow potential
- Critical Heat Impact Radius
- Population in IR
- 9-Mile Radius, Population Density

Table 2-2: Relative Disutility Factors by Injury Severity Level (for Use with 3% or 7% Discount Rates)

AIS Code	Description of Injury	Fractional Fatality Values Value of Life	Dollar Value
AIS 1	Minor	0.003	$28,200
AIS 2	Moderate	0.047	$441,800
AIS 3	Serious	0.105	$987,000
AIS 4	Severe	0.266	$2,500,400
AIS 5	Critical	0.593	$5,574,200
AIS 6	Unsurvivable/Fatal	1.000	$9,400,000







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SSSV (and T&P) effects in the JITF model

Appendix 11 - 1

Type of Detection System	Detection Classification
Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e., loss of pressure or flow) in the system [wells with SCADA]	A
Suitable located detectors to determine when the material is present outside the pressure-containing envelope [daily pressure/temperature/infrared checks]	B
Visual detection, cameras, or detectors with marginal coverage [infrequent visual wellhead inspections, relying on someone to call in a leak]	C
Type of Isolation / Containment System	**Isolation Classification**
Isolation or shutdown systems activated directly from process instrumentation or detectors, with no operator intervention [SSV or SSSV]	A-1
Tubing/Packer or 2nd barrier able to contain the leak	A-2
Isolation or shutdown systems activated by operators in the control room or other suitable locations remote from the leak	B
Isolation dependent on manually-operated valves	C

Table Appendix 11 - 2

Effectiveness/Reliability	Credit Subfactor, Cdi1
Very Low	set total credit to 1
Low	set total credit to 1
Moderate (>80% reliability)	1
Moderately High (>90% reliability)	0.9
Very High (>98% reliability)	0.7

Table Appendix 11 - 3

Detection/Isolation Class	Credit Subfactor, class
A	0.75
A-2	0.5
A-1	0.85
B	0.98
C	1

The JITF model includes very simplified approach to account for SSSV and T&P use:

- SSSV and T&P benefits are introduced as credits in COFI estimates
- Reliability factors and provisions for multiple devices are allowed
- However, workover risks were not included

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Battelle/Sandia model – effects of a shallow-set SSSV on COFI

Subsurface consequences | **Surface consequences**

$$COFI_{\text{with SSSV}} = COFI_{\text{subsurface, all parts}} \times 1 + COFI_{\text{surface, all parts}} \times (1 - Rel_{SSSV})$$

- Safety, environmental, and financial consequences that are caused by subsurface gas release
- Note that there is no SSSV credit (credit=1) for subsurface consequences
- Safety, environmental, and financial consequences that are caused by surface gas release
- SSSV credit, accounting for reliability of this device, is added to the surface consequences

- Note that use of SSSV does not affect the LOFI expression used in the JITF model. However, SSSV-related workover risks must be added
- A deep-set SSSV would be effective against both surface and sub-surface releases – in this case, a modified expression with both surface and sub-surface credits can be used

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Battelle/Sandia model – workover LOFI estimate

$$LOFI_{workover} = Frequency_{workovers} \times Likelihood\ of\ failure_{workover} \times Credit_{mgm\text{-}workover}$$

Note that this is the net increase of workover likelihood of failure introduced by the use of SSSV.

Frequency of SSSV-related workovers, range of values based on operators' experience

Likelihood of failure per workover operation, range of values based on operators' experience

$Credit_{mgm\ workover}$ - management credit similar to **$Credit_{mgm}$** used in the JITF model LOFI estimation

- Note that introduction of SSSV may increase complexity for all workovers, including workovers that are not directly related to SSSVs.

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Battelle/Sandia model – COFI estimate for workovers

$$COFI_{workover} = COFI_{subsurface,\ all\ parts} \times 0 + COFI_{surface,\ all\ parts} \times 1$$

Workover operations are unlikely to cause subsurface release. Setting this part of credit to zero eliminates all subsurface-related consequences

Safety, environmental, and financial consequences that are caused by surface gas release during workover. Note increased safety consequences due to presence of workers performing the workover.

There is no credit (Credit=1) given to surface part of consequences during workovers.

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Workover risks – recent real-world incident

https://www.kbtx.com/video?vid=567411232

An accident at Chesapeake Energy gas well in Texas:

- The accident occurred during workover operations on January 29, 2020
- Ignition of natural gas caused a fire
- Three workers were killed, one sustained serious burns.
- This incident, while providing a reflection on the idea of the risk model we are using and how we are modeling such risk potential, is a sobering reminder of the importance of focusing on human safety - especially to the rig workers who are directly in harm's way with the least chance of escape.

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Representative well types – estimates of well construction and well capability types

Battelle-Sandia team estimate of well construction date (range), pressure, rate capability, and feed volume capability

	lortlovol	lortmidvol	lorthivol	hirtlovol	hirtmidvol	hirthivol	total wells	pct of total
pre1950 lopsi	1201	1289	780	55	128	63	3514	25.2%
pre1950midpsi	269	451	1902	78	188	565	3452	24.8%
pre1950hipsi	7	0	36	0	42	115	199	1.4%
50-69 lopsi	1078	655	221	76	80	364	2473	17.8%
50-69 midpsi	163	215	469	95	243	1293	2477	17.8%
50-69 hipsi	15	0	36	0	37	245	333	2.4%
70-89 lopsi	81	19	93	14	37	81	324	2.3%
70-89 idpsi	56	117	76	65	178	167	658	4.7%
70-89 hipsi	6	0	7	4	54	185	255	1.8%
90+ lopsi	7	0	0	5	9	0	21	0.1%
90+ midpsi	24	0	0	36	101	26	186	1.3%
90+ hipsi	0	0	0	6	22	16	43	0.3%
Total Wells	2905	2744	3617	433	1117	3117	13932	
Pct of Total	20.9%	19.7%	26.0%	3.1%	8.0%	22.4%	13932	

			<1% of wells
pressure class (<1000, 1000-2749, and >2749psi)	1%	139	1-2% of wells
feed volume (total reservoir volume) <10 Bcf, 10-30 Bcf, and >30 Bcf	2%	279	2-5% of wells
rate capability using average well rate for field max deliverability: low = <5 mmcfd average, hi = >5 mmcfd	5%	697	5-10% of wells
	10%	1,393	>10% of wells

Michanowicz at al:

- 2694 "repurposed" wells constructed prior to 1979
- 2715 total "repurposed" wells
- 210 "repurposed" wells drilled prior to 1917
- total data set of 14138 wells

Source: D.R. Michanowicz at al. Environ. Res. Lett. 12 (2017) 064004

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Battelle/Sandia model and its goals

Original JITF risk model

Battelle/Sandia additions for SSSV effects

Typical UGS well designs common in industry

Typical reservoir volumes, pressures, range of population densities

Input collected during this workshop, from industry and from PHMSA

Risk model that accounts for SSSV use in UGS wells, which is:

- Quantitative
- Practical
- Easy to implement with available data
- Adopted by regulators and industry as a valid approach to evaluate UGS well risks and SSSV use.
- Consistent with API 1171 procedures

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Note

The presented model equations are preliminary and may be modified by the Battelle/Sandia team. The final version of the model will be provided in the final project report.