FOR ILLUSTRATIVE PURPOSES

Rolling Up Operational Risk at PG&E

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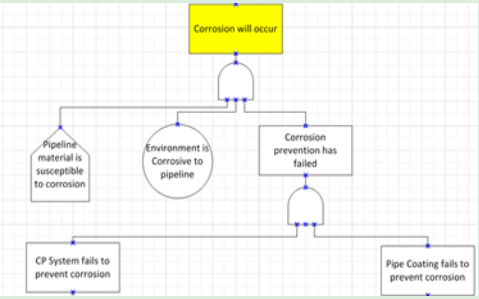
Quantitative Modeling Initiative

PG&E Gas Operations has embarked on an initiative to improve risk quantification, the accounting of uncertainty, and implementation of probabilistic assessment techniques to improve decision making

Probabilistic / Mechanistic Modeling

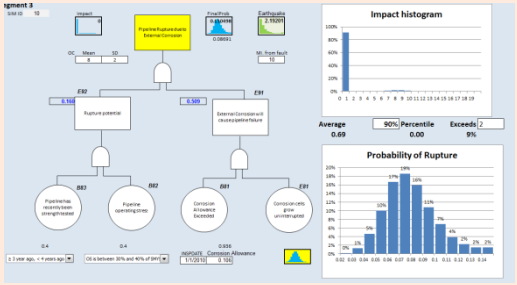
Probabilistic Risk Assessment – Fault & Event Trees

Benchmarked with the nuclear PRA team to begin developing fault and event trees that produce *probabilities* for pipeline ruptures for specified assets and risks as the component/segment level



Stochastic Probabilistic Modeling of "Roll-Up" Risks

- Further developing the PRA's to include *simulations* that can adequately account for *uncertainty* using *innovative* techniques of SIPs
- This technique will allow Gas Operations to *aggregate (roll up)* simulated probability distribution from the component/segment level to the system/enterprise level



Probabilistic Modeling – Transmission Pipeline

Where we were: SME-Driven Risk Management

- Do not have **probabilistic** representations of risk in Enterprise Risk Management process
- Heavily SME-driven without capturing **uncertainty** of risk scores
- Could not **aggregate** risk across Gas Operations to a system level

What we are doing: Exploring Probability Management

- Developing prototype **simulations** of Transmission, Distribution, and Storage asset families
- Addressing the *Flaw of Averages* by accounting for **uncertainty**
- Developing prototype **risk aggregation** across multiple assets

Where we are going: Fully Integrated Risk Management

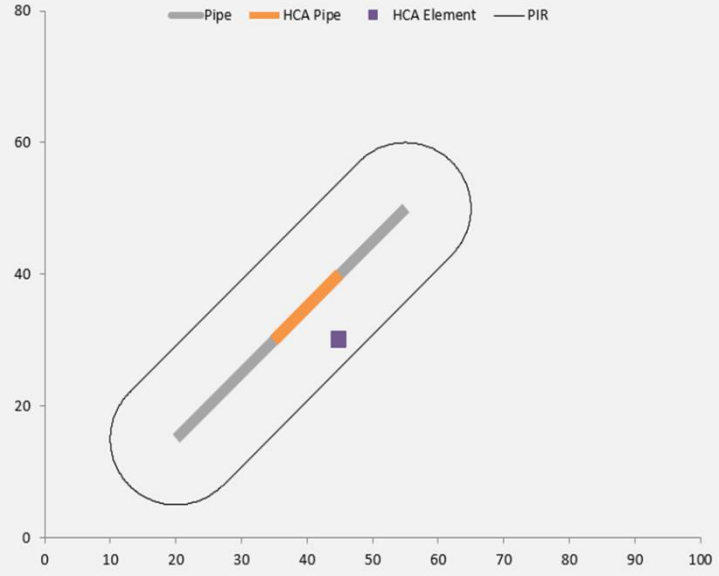
- **Simulations** informed by SMEs and SMEs informed by simulations
- **Quantitatively aggregating** risk across Gas Operations to a system level
- **Optimal portfolios of mitigations** - trade off risk vs cost

HCA Element	LONG	LAT
Center	45	30

PIR Radius	10

Pipe	LONG	LAT
Start	20	15
End	55	50

Length	Pipe	HCA	Non HCA
	49.50	14.14	35.36



Event Probabilities	HCA	Non HCA
P(LOC)/mi.	1.500%	2.0%
P(Ignite|LOC)	50%	50%

Impact | Event	HCA in $M		Non HCA in $M	
	Mean	SD	Mean	SD
LOC	4	1	0.5	0.01
Ignite	20	2.5	1	0.2

A RiskRollup™ Module

From AnalyCorp Inc.

Risk Output	HCA	Non HCA	Combined
Chance of an Event	20.8%	70.7%	77.0%
Histogram of Impact Given LOC	2.7 Damage in Millions 27	0.2 Damage in Millions 2	2.8 Damage in Millions 28
Average	2.54	0.53	3.07
Percentile	95%		
	20.33	1.21	20.82
Threshold	5.00	0.50	10.00
Chance	12%	53%	11%
Tail Average	18.13	0.84	20.62

SIPmath™ Design Study: Dynamic Segment with Potential HCA Element 4/5/2016

6 Phase Framework

Phase/Focus	Phase 1 Historical Asset Condition	Phase 2 Time Dependence	Phase 3 Adverse Events
Function / Purpose	Data collecting and analysis of available asset data	Predict corrosion growth rates	Simulated probabilities of pipeline ruptures and leaks
Inputs	ILI Data ECDA Data Strength Test Data	Phase 1 Outputs + Time since inspection Soil Characteristics CP Performance Coating Performance Leak History*	Phase 2 Outputs + Pipeline MAOP Pipeline Diameter Pipeline Thickness Pipeline SMYS
Outputs (SIPs)	Anamoly geometry	Predicted current anamoly geometry	Pipeline rupture and leak probabiliities per mile
Complexity	Medium (ECDA Data) Low (ILI Data)	High	Low
Technique / Approach	Descriptive Analytics; Predictive Analytics	Predictive Analytics; Simulation	ASMEB31.8G Standard (Modified)

Phase/Focus	Phase 4 Adverse Consequences	Phase 5 Mitigation Impacts	Phase 6 Risk-Based Decisions
Function / Purpose	Simulate leak and rupture consequences	Simulate mitigation impacts to quantify risk reduction	Produced optitmized scenario's of mitigation portfolios
Inputs	Phase 3 Outputs + Total Occupancy Count Average Occupancy Count Leak repair costs* Reliability Impacts	Phase 4 Outputs + Mitigation Benefits	Phase 5 Outputs + Mitigation Costs Resource Constraints System Constraints Financial Constraints Compliance Constraints
Outputs (SIPs)	Risk associated to pipeline rupture or leak (CoF and LoF)	Forecasted risk reductions	Scenario's of mitigation portfolio's and risk tradeoff's
Complexity	Low (Safety) Medium (Reliability)	Medium?	High
Technique / Approach	Predictive Analytics		Presciptive Analytics

Descriptive Analytics	Use of data aggregation and data mining techniques to provide insight into the past. "What has happened?"
Predictive Analytics	Use of statistical models and forecasts techniques to understand the future. "What Could Happen?"
Prescriptive Analytics	Use of optitmization and simulation alogorithms to advice on possible outcomes. "What should we do?"

“Go/No-Go” Probabilistic Decision Process

- Quantitative model being developed to describe the customer outage risk of executing safety projects during high forecasted demand periods
- Model takes into account the following uncertainties:
  - Temperature weather forecasts, customer demand at a given temperature, gas system capacity model assumptions