Joint Intervenor Approach – Test Drives Results Presentation

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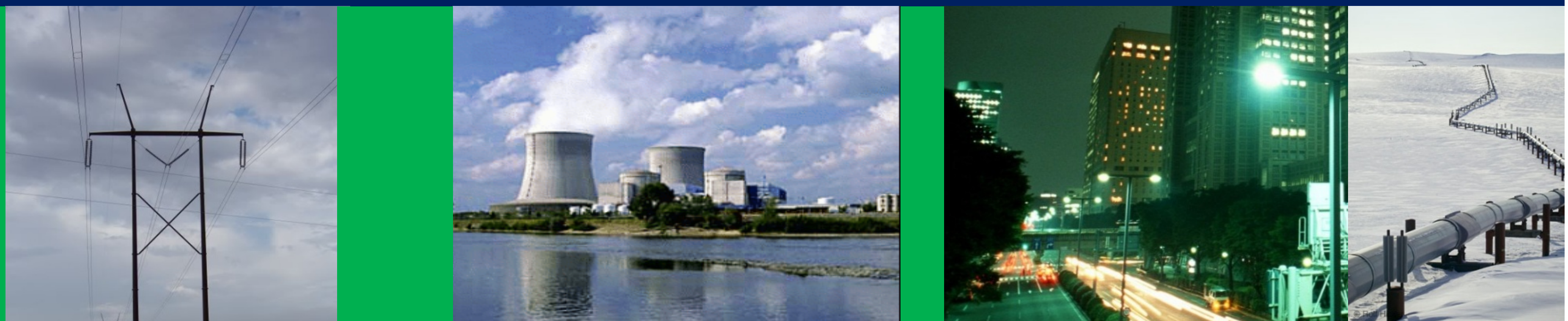


Overview of Joint Intervenor Approach

Test Drive Process

(Day 1, Morning Session)

JIA Test Drive Background

- D.16-08-018 adopted JIA (or utility equivalent features) on an interim basis, subject to this test drive process
- The JIA test drive relies on information provided by the utilities to “plug into” the methodology
- Results should be considered illustrative
- In a real-world implementation, follow-up to validate information provided by utilities would be warranted in some cases

Summary of JIA Reports Provided on October 13th

- An overall Test Drive Report
  - Summarizes Test Drive process we followed, analysis we performed and results of the five test problems
  - Includes attachment describing Results of the January 2017 Working Group sessions to build the multi-attribute value function for the test drives
- Detailed Reports for each test problem
  - Include technical appendices
  - Supporting Excel worksheets provided
  - If overall Test Drive Report does not have detail you're looking for, consult the Detailed Report
- We'll do our best to summarize the key information in these workshops, but the complete story is in the Reports

Basic Principle - Risk

- Joint Intervenor Approach (JIA) defines risk as the **uncertain occurrence of a failure event**.
  - For example a risk would be a pipeline rupture or an overhead wire falling.
- A failure event can have adverse consequences
  - For example the event causes injuries or deaths or causes loss of power to customers.
- Both uncertainty and failure must be present for situation to be considered risky
  - If no uncertainty → no risk, just a bad outcome
  - If no bad outcome possible → no risk

Risk (continued)

- Risk is measured as an <u>expected</u> value, based on LoF and CoF;
  - Risk is <u>not</u> a probability distribution
  - <u>LoF is a single number</u>: a failure event occurs with some probability. (You cannot have a probability distribution of a probability)
  - Consequences of failure can be uncertain; if so, they are described by a probability distribution that incorporates all possible consequence levels (e.g., from minor to catastrophic)

- Risk <u>reduction</u> is the difference between the pre- and post-mitigation risk values
  - Equals the difference in two <u>expected</u> values, hence it is a number

Risk (continued)

- Example: Operating OH Conductor is risky. Why? Because a wires down event may occur and, if so, have adverse consequences, <u>regardless</u> of the specific cause of the wires down event

- Example: The workplace is risky. Why? Because workplace violence can occur, whether caused by employees or external actors, and have adverse consequences.

Joint Intervenor Test Drive Approach: Five Steps

1. Build Multi-Attribute Value Function
2. Develop Condition- Dependent Hazard Rates for each asset or group of assets
3. Develop probability distributions for CoF for each asset
4. Identify mitigation alternatives, specify post mitigation LoF and CoF
5. Identify optimal mitigation strategy, including identifying events having the largest pre-mitigation risk

Step 1: Build a Multi-Attribute Utility Function: Purpose

- MAVF enables us to capture all of the impacts associated with failure events in a single measure
  - Aggregate impacts into a single measure that can be used to compare impacts of risk mitigations
  - Example: Event A has safety and electric reliability impacts. Event B has environmental and financial impacts. MAVF allows us to calculate and compare these different consequences in a consistent manner

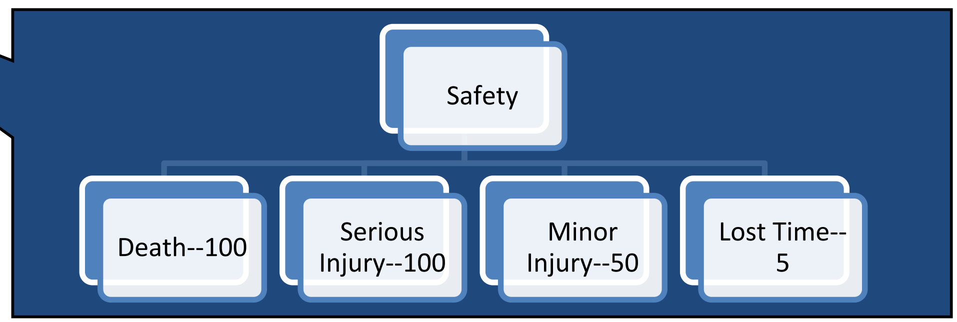
Step 1: Build a Multi-Attribute Utility Function: Definitions

- Attribute: describe what matters to the utility; observable, measurable; changing attribute *level* has value implications; can be changed by mitigation alternatives
- Natural Units: how an attribute is measured; $, injuries, hours, voltage; number of customers, …
- Attribute Range: minimal and maximal levels of any attribute
- Attribute Scale: *constructed* scale based on natural units; relative value of changing level of a single attribute; varies by attribute.
- Attribute Weights: relative values of changing levels of multiple attributes; used to compare values of changing levels of all attributes

MAVF Structure: Three Valuation Components

- Scales measure the value of a change in a single attribute's level

- Weights measure relative value of changes in attribute levels



Step 1: Build a Multi-Attribute Utility Function: Summary

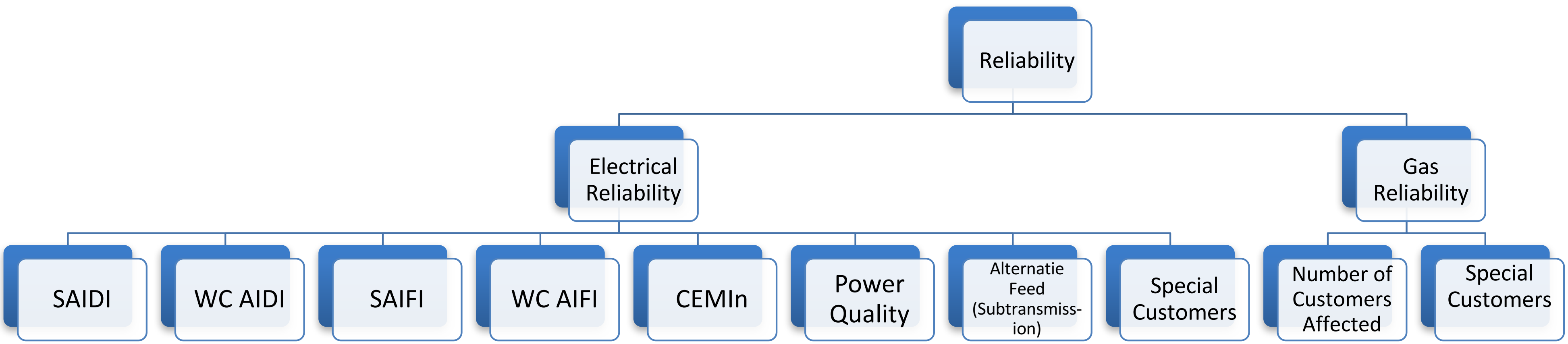
- Identify attributes to measure.
- Define natural units with which to measure those attributes (e.g., deaths, injuries, dollars, etc.)
- Define attribute scaling functions to measure the value of changes in attribute levels
- Determine attribute weights, based on comparisons between changes in attribute levels

Principles of MAVF

- MAVF 1. Attribute Hierarchy Principle
- MAVF 2. Principle of Measured Observations
- MAVF 3. Comparison Principle
- MAVF 4. Risk Assessment Principle
- MAVF 5. Scaled Units Principle
- MAVF 6. Principle of Relative Importance

MAVF 1. Attribute Hierarchy Principle

- **Identify the reasons for risk mitigation – top level attributes**
  - Mitigation alternatives change observed measurements of some attributes
  - Top level attributes are recognizable descriptors of system performance
- **Identify lower-level, measurable attributes**
  - Lower level attributes determine values of highest level attributes
  - Lower level attributes are directly observable and have measured observations that change as a result of implementing mitigations



MAVF 2. Principle of Measured Observations

- Observation/Measurement
  - Observation--What could happen, span the space identifying all possible consequences
  - Measurement--How much happens, create the natural units
- Example: If a failure occurs, how many serious injuries can result?

MAVF 2. Principle of Measured Observations: Example

- Serious injuries
- Possible events: pipeline segment leak and ignition, workplace violence event, fallen wire, workforce error, …
- Minimum number of serious injuries--0 injuries
- Maximum number of serious injuries—1000 injuries

- Range: 0 500 1000
- Question: How to value increasing number of injuries?

MAVF 3. Comparison Principle

- Relate actual consequences to other known and measurable attribute levels (identify proxy)
- Example: Customer Satisfaction
- Proxy: Measure the arrival rate of complaints and apply principles of measured observations and scaled units to numbers of complaints.

Scale	Natural Units (Customer Satisfaction)	Natural Units (Proxy)
0:	Best power quality	(0 complaints/wk)
20:	?	(1 complaint /wk)
70:	?	(5 complaints /wk)
100:	Worst power quality	(25 complaints /wk)

MAVF 4. Risk Assessment Principle

- If attribute levels are uncertain, ask about that uncertainty directly.
- Use either statistical expected values or well-defined uncertain situations (e.g., toss a coin; if "heads" then 2 deaths; if "tails", then 0 deaths)
- Example: risk of deaths
- Use of percentiles: 10-50-90 range
  - Median, or 50th percentile: 2 deaths
  - 90th percentile: 8 deaths
  - 10th percentile: 1 death
  - Convert percentile values into an expected value

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MAVF 5. Scaled Units Principle

- Scaled Value is a *constructed* scale based on natural units.
- Scaling functions between 0 and 100 (unweighted) risk units.
- Natural units are readily observable and measurable.
- Scaled units specify relative value of changes.
- Part 1: Identify important stops on range of natural units.
- Part 2: Apply scale intervals to set values of constructed scale.
- Examples:
  - 1. Serious Injuries: linear scale because value of avoiding an injury does not depend on level of injuries
  - 2. Power Quality: value of changes in voltage level depends on level of voltage

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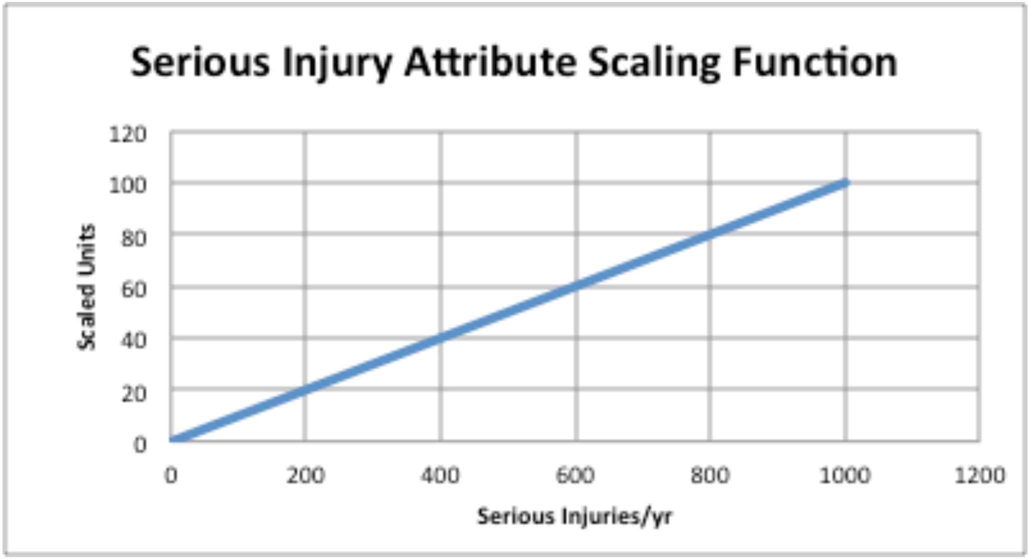
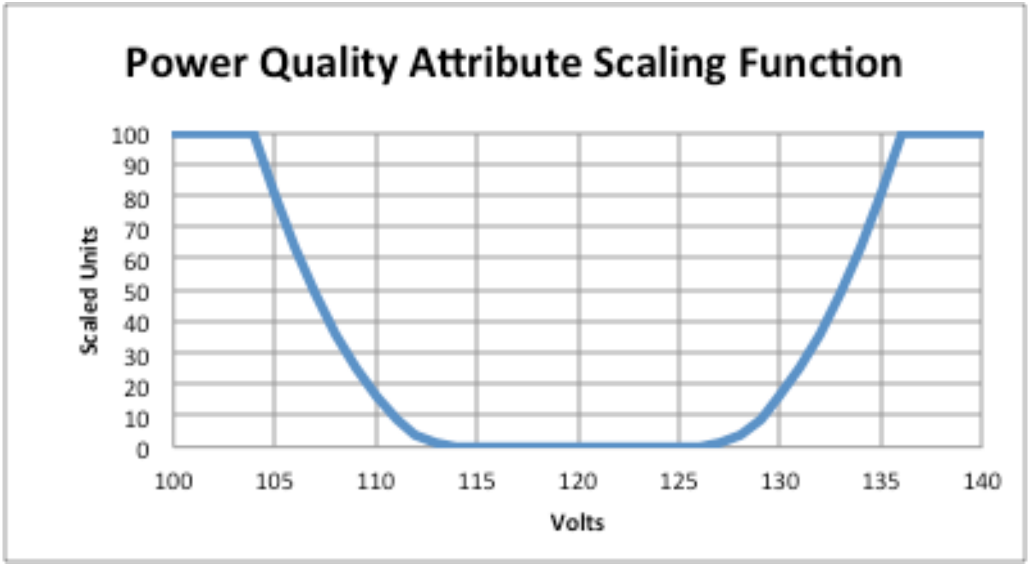
MAVF 5. Scaled Units Principle: Serious Injuries Example

- If the value of avoiding an injury/yr does not depend on the present level of injuries/yr, then the scale is linear
- Equivalently, if the value of a change in attribute level depends only on the amount that is changed, then the scale is linear.



MAVF 5. Scaled Units Principle: Power Quality Example

- Voltage less than 104 or greater than 136 are worst-case outcomes. Thus, they are “worst case” values and have scale values of 100.
- Voltage within the range 114 – 126 volts is satisfactory and equally good. Thus, scale value = 0.
- The value of voltage outside that interval decreases nonlinearly (assumed quadratically) until the bounds of 104 or 136 are reached



MAVF 6. Principle of Relative Importance

- Purpose is to measure tradeoffs between attributes (safety, reliability, cost ($),…)
- Part 1: Range Preference -- Relative importance of moving an attribute the full span (worst to best)
- Part 2: Strength of preference assigns actual measurement (e.g. poker chips, $\leq$ 100) to the relative importance of the range
- Example: Deaths compared to Financial Consequences
  - Part 1: $(100 \rightarrow 0)d > (\$1B \rightarrow \$0)fc$
  - Part 2: $(100 \rightarrow 0)d = 100 \rightarrow (\$1B \rightarrow \$0)fc = 25$
  - Conclusion: $W_{fc} / W_d = 25/100 \rightarrow W_{fc} = 0.25\, W_d$
  - Actual Weights: $W_{fc} = 0.0409$, $W_d = 0.1636$
  - Equivalence: $100\ d = 4 \times \$1B \rightarrow 1\ d = \$40M$

MAVF Implementation

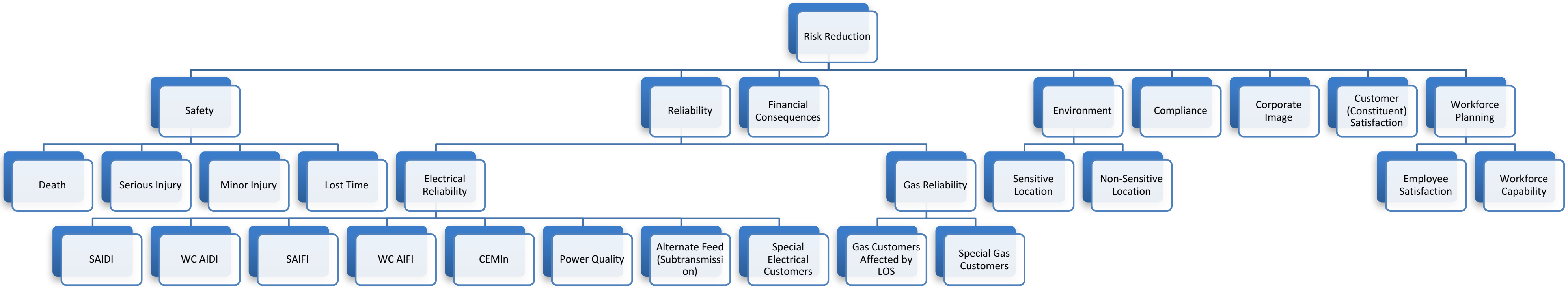
- Utilities chose eight high-level attributes and identified the measurable sub-attributes (e.g., “Safety” [Deaths, Serious Injuries, Minor Injuries, Time Lost])
- Utilities determined attribute ranges (e.g., “Financial” [$0 to $1 billion maximum per event; “Deaths” [0 to 100 maximum])
- Utilities determined scaling function shapes (e.g., linear for deaths, financial; non-linear for reliability, environmental impacts)
- Utilities determined tradeoffs among the changes in different pairs of attribute levels, which were used to calculate the attribute weights.

MAVF Implementation (cont'd)

1. Safety	5. Reliability
2. Financial Consequences	6. Environment
3 Compliance	7. Corporate Image
4. Customer (Constituent) Satisfaction	8. Workforce Planning

- Utilities selected eight top level attributes

MAVF Implementation (cont'd): Complete Attribute Hierarchy



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MAVF Implementation (cont'd): Attribute Weights

Attribute	Attribute Range	Lower-level Weight	Top-level or Proportionally Adjusted Weight	Normalized Weight
SAFETY				
Death	0-100	100	100	0.1636
Serious Injury	0-1,000	100	100	0.1636
Minor Injury	0-10,000	50	50	0.0818
Lost Time	0-1,000	5	5	0.0082
ELECTRICAL RELIABILITY				
SAIDI	0-600	100	25	0.0409
WC AIDI	0-2,000	1	0.25	0.00041
SAIFI	0-6	100	25	0.0409
WC AIFI	0-10	1	0.25	0.00041
CEMIn	0-100,000	1	0.25	0.00041
Power Quality	Within/Outside 120+6	.025	0.00625	0.00001
Alternate Feed	Solve/Not	2	0.5	0.00082
Special Customer	Solve/Not	.025	0.00625	0.00001

MAVF Implementation (cont'd): Attribute Weights

Attribute	Attribute Range	Lower Level Weight	Top-level of proportionally adjusted weight	Normalized weight
GAS RELIABILITY				
Customer Affected by Loss of Service	0-1,000,000	100	25	0.0409
Special Customers	Solve/Not	0.025	0.00625	0.00001
FINANCIAL	0-$1B		25	0.0409
ENVIRONMENT				
Sensitive Area	(Low, 0) – (High, >100)	100	75	0.1227
Non-sensitive Area	(Low, 0) – (High, >100)	10	7.5	0.0123
COMPLIANCE	(No Consequence, Out of Business)		100	0.1636
CORPORATE IMAGE	(Neg, Pos)		2.5	0.0041
CUSTOMER SATISFACTION	0-100%		25	0.0409
WORKFORCE PLANNING				
Employee Satisfaction	0-100%	50	15	0.0246
Workforce Capability	(Neg, Pos)	100	30	0.0491
Sum			611.26875	1.000

Joint Intervenor Test Drive Approach: Five Steps

1. Build Multi-Attribute Value Function
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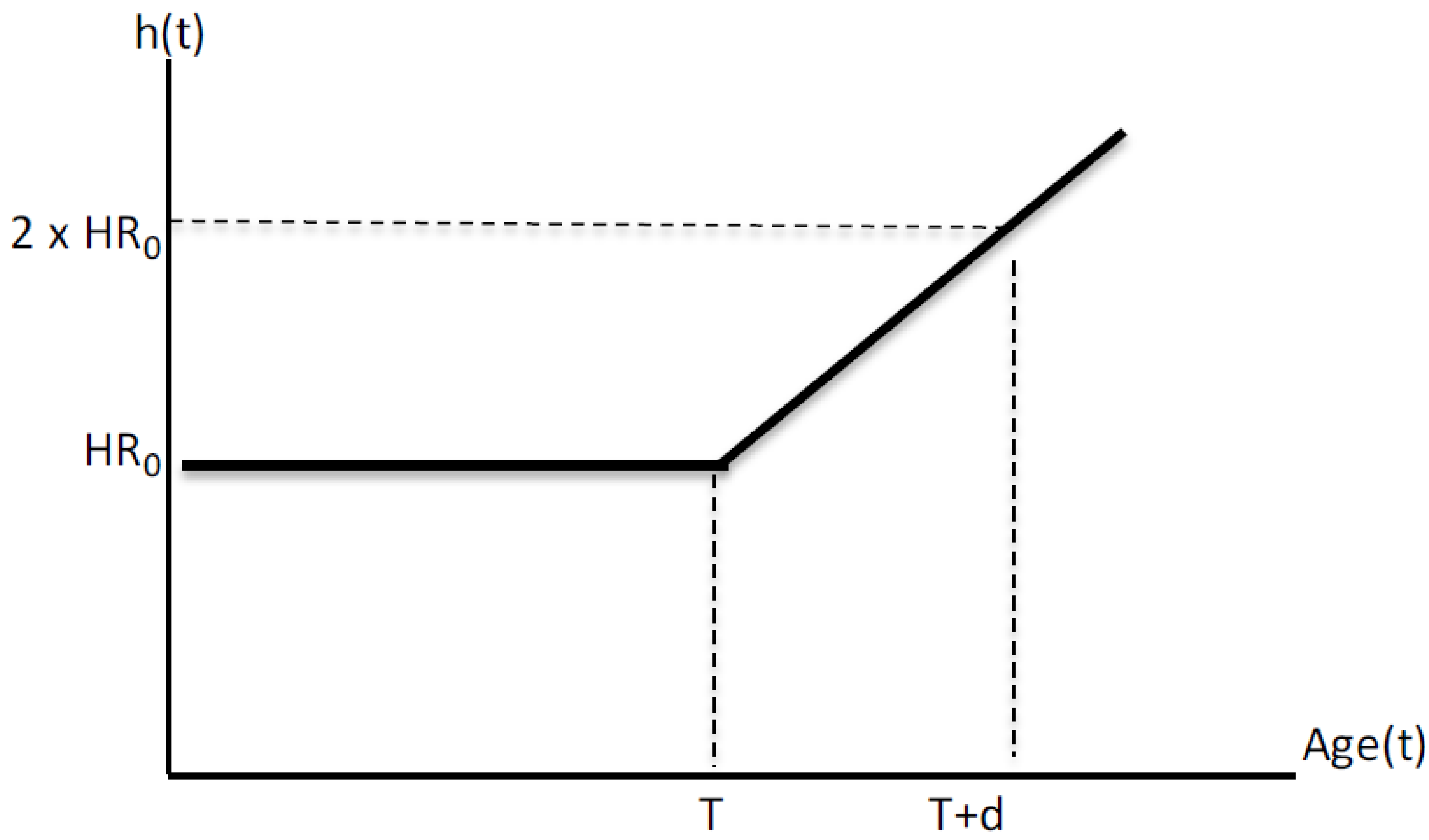
Step 2: Develop Condition-Dependent Hazard Rates (LoF)

- A “hazard rate” measures the probability of failure over a given time period (usually a year)
- Hazard rate depends on the (effective) age of the asset
- Hazard rate depends on operating and environmental characteristics
- Hazard rate depends on the condition of asset
- Asset condition changes over time and is uncertain
- Asset condition can be indirectly observed by testing

Step 2: Estimating LoF

- Estimate LoF based on:
  - What is known about the event (data, SME judgment)
  - Asset condition today and how asset condition can change over time
  - Calculate base hazard rate and use multiplier values supplied by utilities for specific sub-classes of assets (e.g., pipe mfg. before WWII)
  - Include probabilities that outside events (e.g., catastrophic earthquake) can cause a failure event (e.g., pipe rupture)
- Dynamic approach assumes asset condition not known with certainty
  - Use testing to more accurately forecast asset condition and modify LoF
  - Testing is treated as a distinct mitigation alternative (provides information that can affect choice of mitigation strategy)
  - Example: testing wooden poles for strength, ILI for pipe

Step 2: Develop Condition-Dependent Hazard Rates



- "T" is the time (years) when the failure rate begins to increase over its base level.
- "d" is the time for the failure rate to double over its base level

Step 2: Develop Condition-Dependent Hazard Rates

- General Process:
  - Define failure event (pipe rupture with ignition, workplace violence, …)
  - Data/SME judgment to estimate failure events per year
  - Convert failure events/year to the probability of failure (LoF) using what is called the Poisson distribution
  - Identify all factors ("Stressors") that affect failure likelihood (e.g., corroded pipe more likely to fail than uncorroded pipe, workplace violence more likely to take place in dangerous locations, etc.)
    - Stressors are treated as multipliers to the base hazard rate, and affect T and d values
    - Example:, Corroded pipe may be 50% more likely to fail than average, hence a multiplier of 1.50.
  - Identify outside events that cause failure (e.g., earthquakes, dig-in events, etc.)

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Step 3: Develop Probability Distributions for CoF

- For each failure event (e.g. pipe rupture), utilities identify all of the possible consequences of failure
  - Which of the attributes are affected?
- Utilities identify ranges of consequences of failure in terms of attribute levels
- Also asked utilities to provide no-failure, “business-as-usual” consequences
  - If a utility expects some level of adverse consequences as part of normal operations (e.g., a worker might twist his ankle on the job), assuming a no-failure consequence value of zero will over-estimate risk reduction
- Use MAVF and attribute levels to calculate the CoF of a risky situation in risk units

Step 3: Develop Probability Distributions for CoF (cont'd)

- If CoF is certain, then a single level (in natural units) is specified for each attribute
- If CoF is uncertain, we use 10-50-90 percentiles of the probability distribution of CoF to calculate the expected CoF value
  - $E\{CoF\} = 0.3015\ CoF_{.10} + 0.3970\ CoF_{.50} + 0.3015\ CoF_{.90}$ (The coefficients are based on a well-known mathematical technique, called "Gaussian quadrature.")
  - This computation includes the effect of the 90^{th}-percentile tail of the uncertain CoF

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Step 4: Identify Alternative Mitigation Measures

- Utilities provide information on the mitigation alternatives
  - Examples: to reduce wire-down events associated with overhead conductors, can reconductor, put lines underground, etc.; to reduce worker errors, provide computers to all field workers, etc.
- Utilities provide information on how each mitigation affects hazard rates (HR_o, T, d) and stressors
  - Example: replace pipe with brand new pipe reduces the steady-state hazard rate (HR_o by 40%)
- Utilities provide information on the costs (capital and annual expense) of each mitigation measure, and the measure's expected lifetime
- Utilities provide information on post-mitigation CoF levels, similar to Step 3

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Step 5: Analysis and Ranking of Risk Mitigation Alternatives

- Dynamic analysis
  - Identify optimal mitigation strategy (including testing) based on asset age/condition
  - Objective: maximize the expected net present value of risk mitigation over foreseeable future
- Static analysis
  - Identify most cost-effective mitigations
  - Use benefit-cost ratio based on MAVF parameters selected by utilities in Working Group 1 sessions
  - Developed “statistical value of life” estimates as another gauge of reasonableness of safety-related mitigations
- Both approaches analyze asset sub-groups

Step 5: Analysis and Ranking of Risk Mitigation Alternatives

- JIA methodology based on an infinite time horizon
  - Accounts for time value of money and inflation
- Calculate levelized annual costs for each mitigation
  - Based on assumed inflation rate, mitigation lifetime, and utility's discount rate (WACC)
  - Static analysis assumes replacement based on mitigation measure lifetime (provided by utilities)
- RSE = annual risk reduction / levelized cost
  - We typically report in risk units per billion $ of expenditure

Step 5: Alternative Measurement Tools--Benefit-Cost Ratio

- RSE values can be expressed in terms of benefit-cost ratios to gauge actual cost-effectiveness of mitigation alternatives
- Based on MAVF attributes and weights identified by the utilities in the Working Group 1 sessions:
  - $1 billion maximum financial impact and weight of **0.0409**
  - Implies a reduction of $1 billion provides 4.09 in risk unit benefits (recall: risk scale is 0 – 100 units, thus 100 x 0.0409), or **$244.5** million per risk unit ($1 billion / 4.09)
  - Annual Benefit: = (Risk Unit Reduction of Mitigation) x $244.5 million
  - Annual Cost: Annual levelized cost

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Step 5: Alternative Measurement Tools--Statistical Value of Life Estimates

- Compare the implied SVL against other measures of SVL to determine reasonableness
- SVL measures willingness to pay for a small reduction in probability of premature death
  - Used in many government policy analyses (clean air, highway safety)
  - Example: US EPA SVL: $8.4 million (2015$) per SVL
  - Example: US DOT SVL: $9.6 million (2015$) per SVL
- Utility MAVF from Working Group 1 sessions: $40 million
  - Based on 100 death maximum impact, maximum financial impact of $1 billion, weight for deaths of 0.1636, or four times the financial attribute weight of 0.0409.

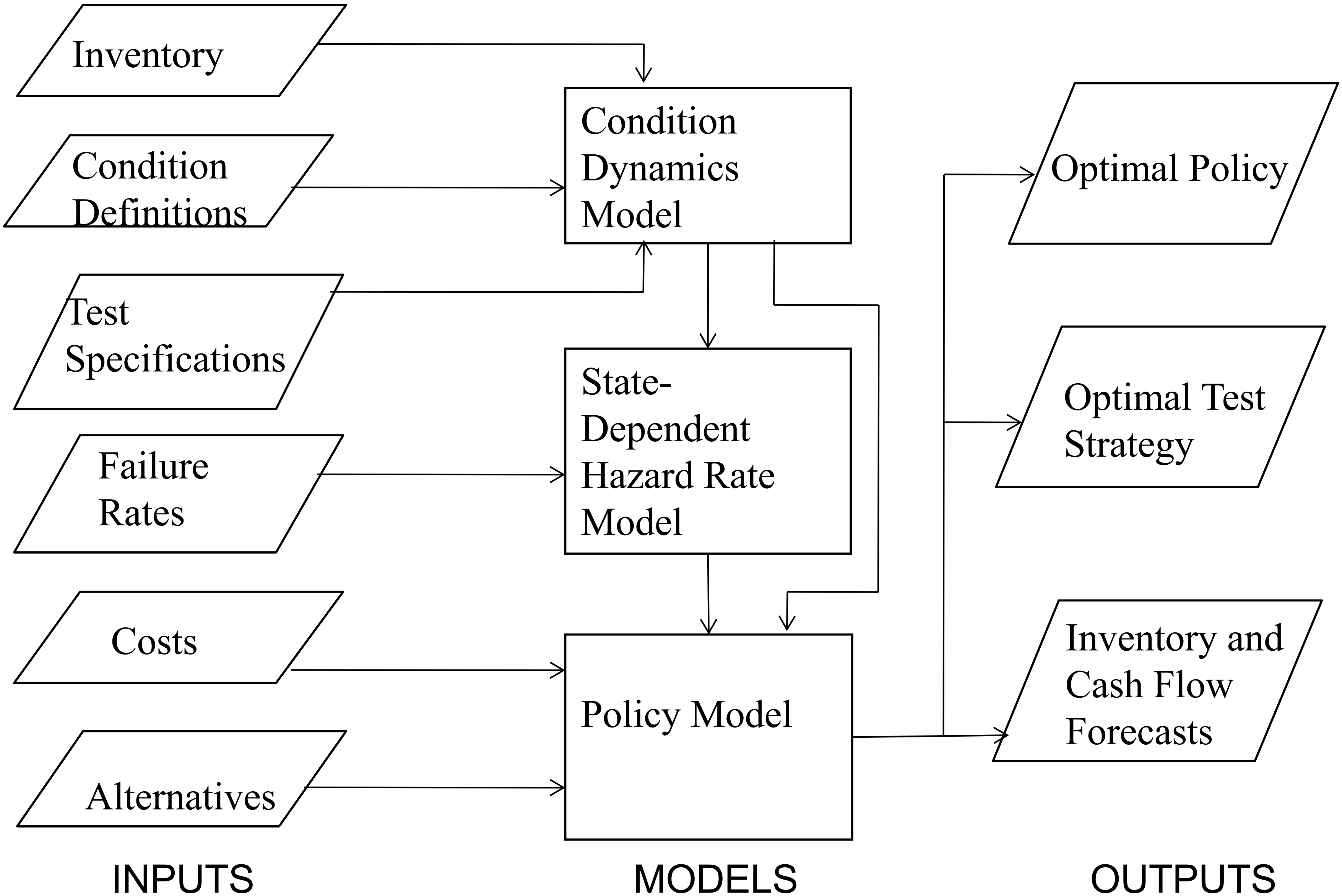
Step 5: Implementing a Dynamic Analysis

1. Define failure event: pipeline leak, OH wire down, etc.
2. Define asset condition (not directly observable) and asset state (observable); both influence LoF
3. Specify condition dynamics – how does asset condition change over time?
4. Specify relationship between p{failure event} and asset condition (condition-dependent hazard rate; LoF)
5. Identify condition tests and test accuracy

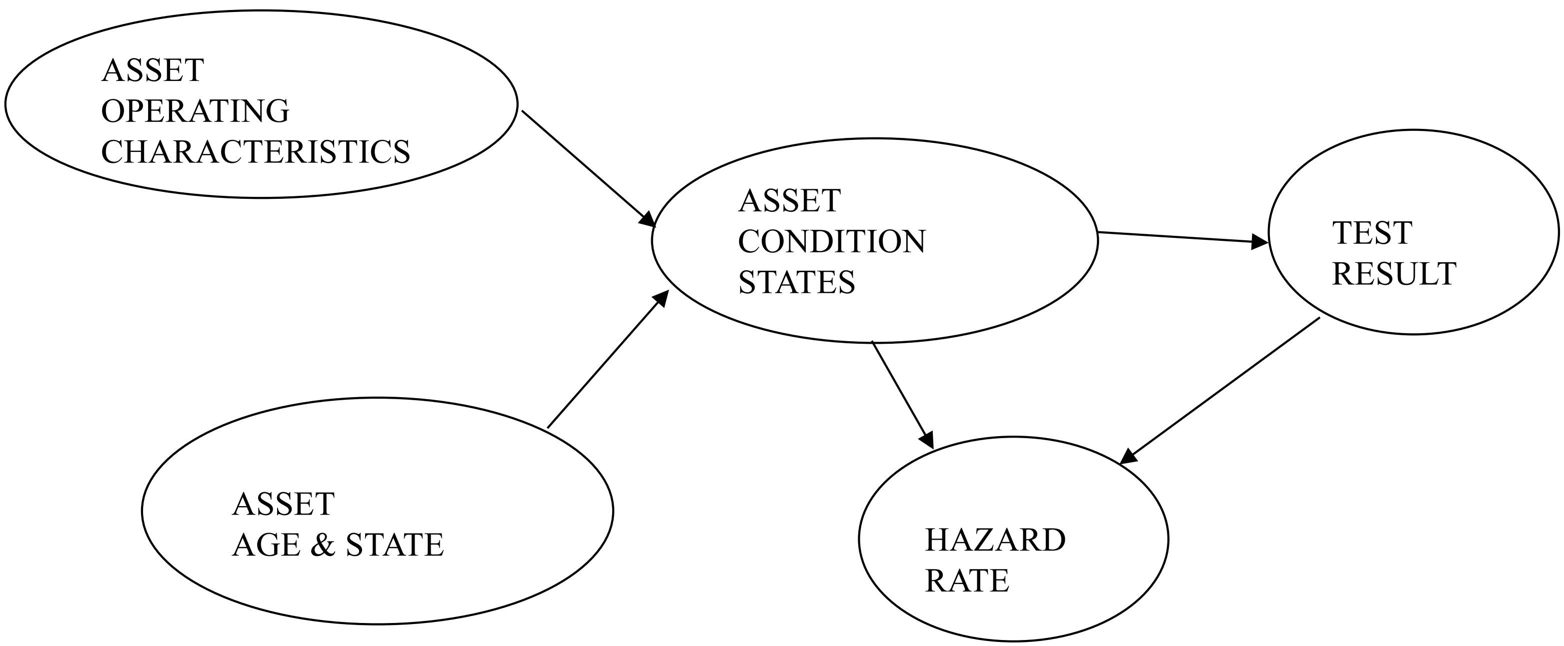
Step 5: Implementing a Dynamic Analysis (cont.)

6. Estimate consequences of failure event (CoF) using MAVF
7. Identify mitigation alternatives that change LoF and/or CoF
8. Estimate changes in LoF and CoF for each mitigation alternative
9. Solve optimization problem: maximize expected present value of Risk Reduction over foreseeable future by choosing kind and timing of mitigation alternatives
10. Sensitivity analysis; policy analysis

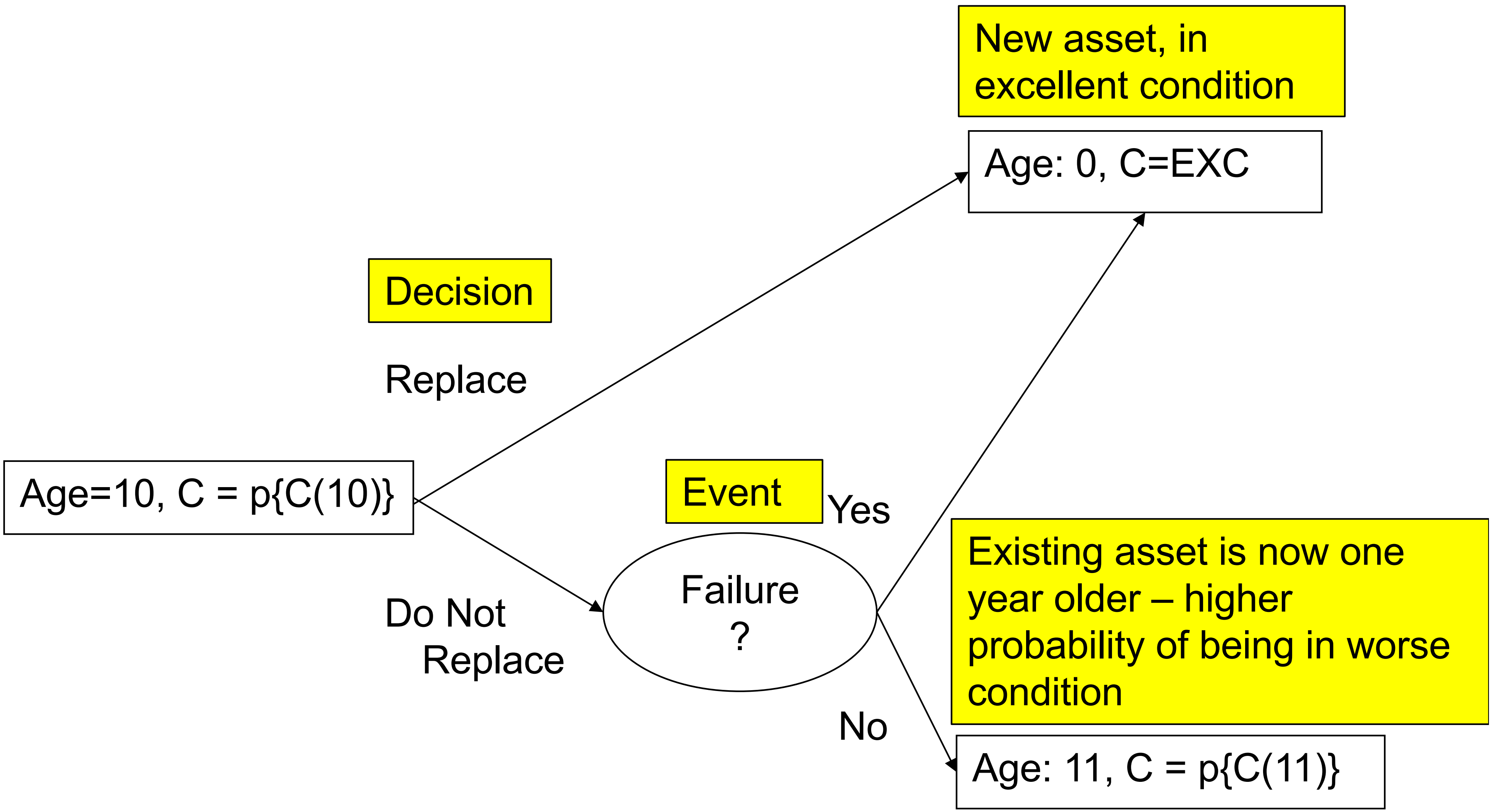
Summary of JIA Dynamic Analysis



Step 5: Dynamic Analysis: Relationship among condition dynamics, test results, and hazard rates



Step 5: Dynamic Analysis: State Dynamics



Summary of Test Drive Problem Results

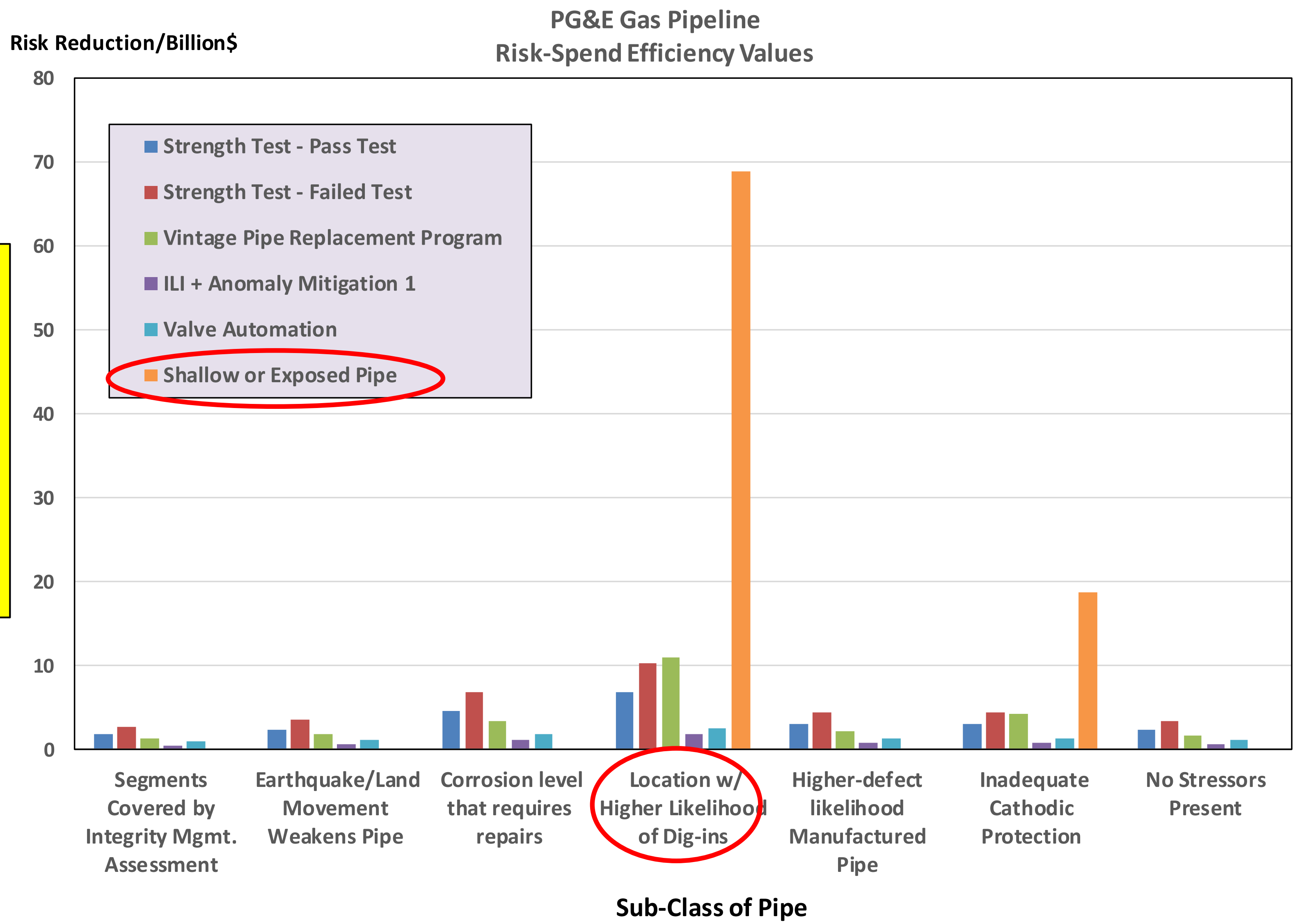
1. PG&E High Pressure Pipeline
2. Sempra High Pressure Pipeline
3. SCE Overhead Conductor
4. SDG&E Workplace Violence
5. PG&E Inadequate Workforce

Test Drive: PG&E High Pressure Pipeline

- Problem: risk associated with pipeline rupture event
  - Tested 34” pipe; mfg: 1950-59; MAOP 800-899; 0.375 thickness
- Mitigation alternatives provided for analysis:
  - (1) Hydrotesting, (2) ILI, (3) valve automation, (4) pipe replacement, (5) relocate shallow/exposed pipe

Test Drive: PG&E High Pressure Pipeline results

Focus on areas with higher likelihood of dig-ins; mitigating shallow/exposed pipe highest RSE



Test Drive: PG&E High Pressure Pipeline (cont'd) Summary of Dynamic Analysis

Optimal Policy compared with run-to-failure; state-dependent policy, policy costs, value of information

COMPARISON TABLE

	OPTIMAL POLICY	USER POLICY	COST SAVINGS
Total PV Cost ($000)	$3,735,678	$7,043,460	$3,307,782

VALUE OF TESTING COMPARISON

	NO TEST	WITH TEST	COST SAVINGS
Total PV Cost $000	$4,104,070	$3,735,678	$368,392

OPTIMAL POLICY

Age	No Failures	1 Failure	2+ Failures
0	No Action	No Action	No Action
1	No Action	No Action	No Action
2	No Action	No Action	No Action
3	No Action	No Action	No Action
4	No Action	No Action	No Action
5	No Action	No Action	No Action
6	No Action	No Action	No Action
7	No Action	No Action	No Action
8	No Action	No Action	Test
9	No Action	No Action	No Action
10	No Action	No Action	No Action
11	No Action	No Action	No Action
12	No Action	No Action	Test
13	No Action	No Action	STRENGTH TEST
14	No Action	No Action	Test
15	No Action	No Action	No Action
16	Test	Test	Test
17	No Action	No Action	STRENGTH TEST
18	Test	Test	STRENGTH TEST
19	No Action	No Action	No Action
20	Test	Test	Test
21	No Action	No Action	STRENGTH TEST
22	Test	Test	Test
23	No Action	No Action	STRENGTH TEST
24	Test	Test	Test
25	No Action	No Action	STRENGTH TEST
26	Test	Test	Test
27	No Action	No Action	STRENGTH TEST
28	Test	Test	Test
29	No Action	No Action	STRENGTH TEST
30	Test	Test	Test
31	No Action	No Action	STRENGTH TEST
32	Test	Test	Test
33	No Action	STRENGTH TEST	STRENGTH TEST
34	Test	Test	Test
35	No Action	No Action	STRENGTH TEST
36	Test	Test	Test
37	No Action	STRENGTH TEST	STRENGTH TEST
38	Test	Test	Test
39	No Action	STRENGTH TEST	STRENGTH TEST
40	Test	Test	Test

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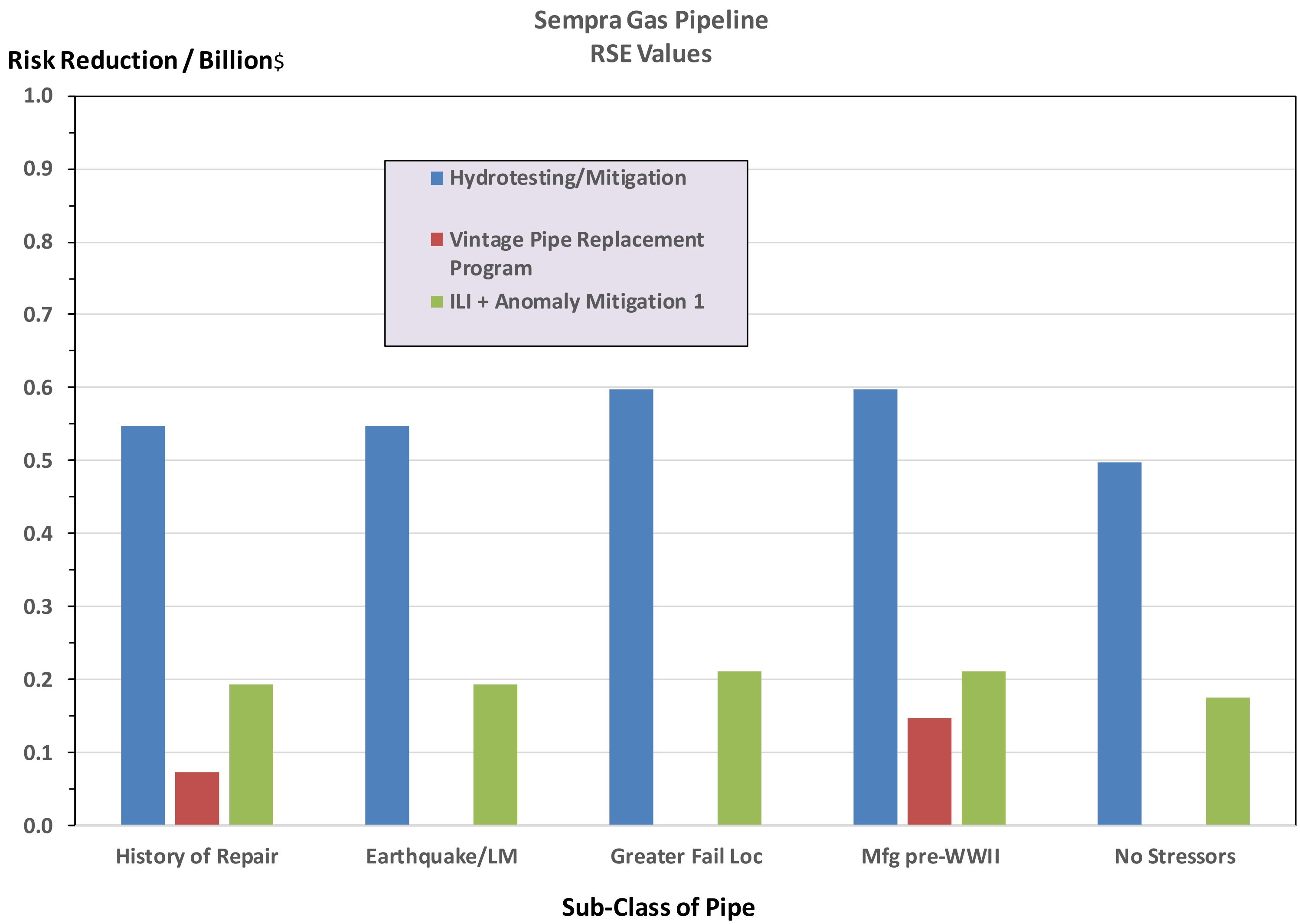
Test Drive: Sempra High Pressure Pipeline

- Problem: “failure” defined broadly to include pipe that is still operable but cannot satisfactorily perform intended function (much broader definition than PG&E)
  - Considered entire Sempra high pressure gas pipeline system
- Mitigation alternatives provided for analysis:
  - (1) hydrotesting/mitigation; (2) ILI/mitigation; (3) vintage pipe replacement

Test Drive: Sempra High Pressure Pipeline results

Hydrotesting has highest RSE.

Pipe replacement lowest RSE.



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Test Drive: SCE Overhead Conductor

- Problem: Wires down event
- Mitigation alternatives provided for analysis:
  - (1) reconductoring, (2) aerial cable, (3) tree wire, (4) undergrounding
- SCE told us all circuits are different, because LoF depends on each circuit's characteristics
  - Analyzed and ranked all 3,800+ circuits
- Results: reconductoring had highest RSE values, then aerial cable
  - SCE assumed no fixed costs, therefore results show shortest circuits generally have largest RSE values

Circuit No.	Length (miles)	RSE Reconductor
2018	2.0	570.6
2299	314.1	0.02

Test Drive: SCE Overhead Conductor (cont'd)
Summary of Dynamic Analysis

Optimal Policy compared with run-to-failure; state-dependent policy, policy costs, value of information

COMPARISON TABLE

	OPTIMAL POLICY	USER POLICY	COST SAVINGS
Total PV Cost (000's)	$13,704	$18,911	$5,207

VALUE OF TESTING COMPARISON

	NO TEST	WITH TEST	COST SAVINGS
Total PV Cost (000's)	$15,731	$13,704	$2,027

OPTIMAL POLICY

Age	No Failures	1 Failure	2+ Failures
0	No Action	No Action	No Action
1	No Action	No Action	No Action
2	No Action	No Action	No Action
3	No Action	No Action	No Action
4	No Action	No Action	No Action
5	No Action	No Action	No Action
6	No Action	No Action	No Action
7	No Action	No Action	No Action
8	No Action	No Action	No Action
9	No Action	No Action	No Action
10	No Action	No Action	No Action
11	No Action	No Action	No Action
12	Test	Test	Test
13	No Action	No Action	No Action
14	No Action	No Action	No Action
15	No Action	No Action	No Action
16	Test	Test	Test
17	No Action	No Action	No Action
18	No Action	No Action	No Action
19	No Action	No Action	No Action
20	Test	No Action	Test
21	No Action	No Action	No Action
22	No Action	No Action	No Action
23	No Action	No Action	No Action
24	Test	Test	Test
25	No Action	No Action	No Action
26	No Action	No Action	No Action
27	No Action	No Action	No Action
28	Test	Test	Test
29	No Action	No Action	No Action
30	No Action	No Action	No Action
31	No Action	No Action	No Action
32	Test	Test	Test
33	No Action	No Action	No Action
34	No Action	No Action	No Action
35	No Action	No Action	No Action
36	Test	Test	Test
37	No Action	No Action	No Action
38	No Action	No Action	No Action
39	No Action	No Action	No Action
40	Test	Test	Test

Test Drive: PG&E Workforce Adequacy

- Problem: Inadequately trained workforce more likely to make errors in the field
  - Error frequency depends on tenures of employees and skill levels
- Mitigation alternatives provided for the analysis:
  - (i) portable technology access – to crew leads, to everyone, etc.; (ii) 24/7 technical support desk; (iii) work scheduling; (iv) expanded use of qualification cards (electric only)
- Results:
  - RSE depends on employee tenure
  - 24/7 help desk largest RSE value
  - All mitigations cost-effective

Test Drive: SDG&E WPV Event

- Problem: risk associated with active shooter events caused by (i) employees or (ii) outside actors
- Mitigation Alternatives provided for analysis:
  - (1) active shooter training; (2) enhanced building physical security.
- Results:
  - Training much higher RSE than building physical security, but both cost-effective (289.1 risk units/billion$ vs. 11.1 risk units/billion$)
  - RSE of training depends on how “effective” training is – do employees forget their training over time? How many employees must be retrained each year?

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Detailed Test-Drive Results (Day 1, Afternoon Session)

1. PG&E High Pressure Pipeline
2. Sempra High Pressure Pipeline
3. SCE Overhead Conductor
4. SDG&E Workplace Violence
5. PG&E Inadequate Workforce

PG&E High Pressure Gas Pipeline

- Failure Event: pipe rupture event
  - PG&E informed us that different categories of pipe have different failure rates, CoF, etc.
  - Test-drive focused on single most common type of pipe on PG&E system: 34-inch, mfg. 1950-59, MAOP 800-899; 0.375 thickness, SYMS=52000
  - (Note: PG&E's own JUA test drive looks at its entire system of pipe jointly)
- Mitigation alternatives provided for analysis:
  - (1) Hydrotesting, (2) ILI, (3) valve automation, (4) pipe replacement, (5) relocate shallow/exposed pipe
- Outside events:
  - Overpressure event: (1 every million years)
  - Catastrophic earthquake (1 every 333,000 years)
  - Dig-in event (1 every 59,000 years)

PG&E High Pressure Gas Pipeline (cont.)

- In addition to static analysis, performed dynamic analysis to illustrate that part of methodology
  - Analyzed same group of pipe as static analysis
  - Assumed pipe condition deteriorates over time, increasing the likelihood of rupture events
  - Examined the value of testing pipe condition
- Dynamic analysis identifies the optimal policy in light of asset changes over time
  - Maximizes expected present value of risk reduction subject to constraints

PG&E HP Pipeline Static & Dynamic Analysis: Base Hazard Rate

Item	Pipeline		
1. Frequency (Avg. Segment Failure Events /year)	0.10		
Expected years per event	10.0		
Total Number of Segments	**1,046**		
Average Segment length (miles)	**0.1746**		
PG&E Hazard Rate Parameters	**HR_0**	**T**	**D**
	0.00005	**30.0**	**20.0**
2. Hazard Rate Parameter Multipliers	HR_0	T	D
a. Segments Covered by Integrity Mgmt. Assessment	0.80	1.50	1.50
b. Earthquake/Land Movement Weakens Pipe	1.05	1.00	1.00
c. Corrosion level that requires repairs	2.00	0.30	0.30
d. Location w/ Higher Likelihood of Dig-ins	3.00	1.00	1.00
e. Higher-defect likelihood Manufactured Pipe	1.30	0.70	0.70
f. Inadequate Cathodic Protection	1.30	0.60	0.60
g. No Stressors Present	1.00	1.00	1.00
3. Hazard Events that Are Assumed to Cause a Segment Failure	**Expected Events/Segment/ Year**	**p(Seg Failure & Event)**	
a. Overpressure Event	0.0000001	0.0000001	
b. Catastrophic Earthquake	0.0000030	0.0000030	
c. Dig-in Event	0.0000170	0.0000170	
TOTAL	**0.0000201**	**0.0000201**	

Note: PG&E data implies actual base hazard rate is 0.000096, about 2x PG&E assumed value of 0.00005.

Our analysis based on PG&E assumption

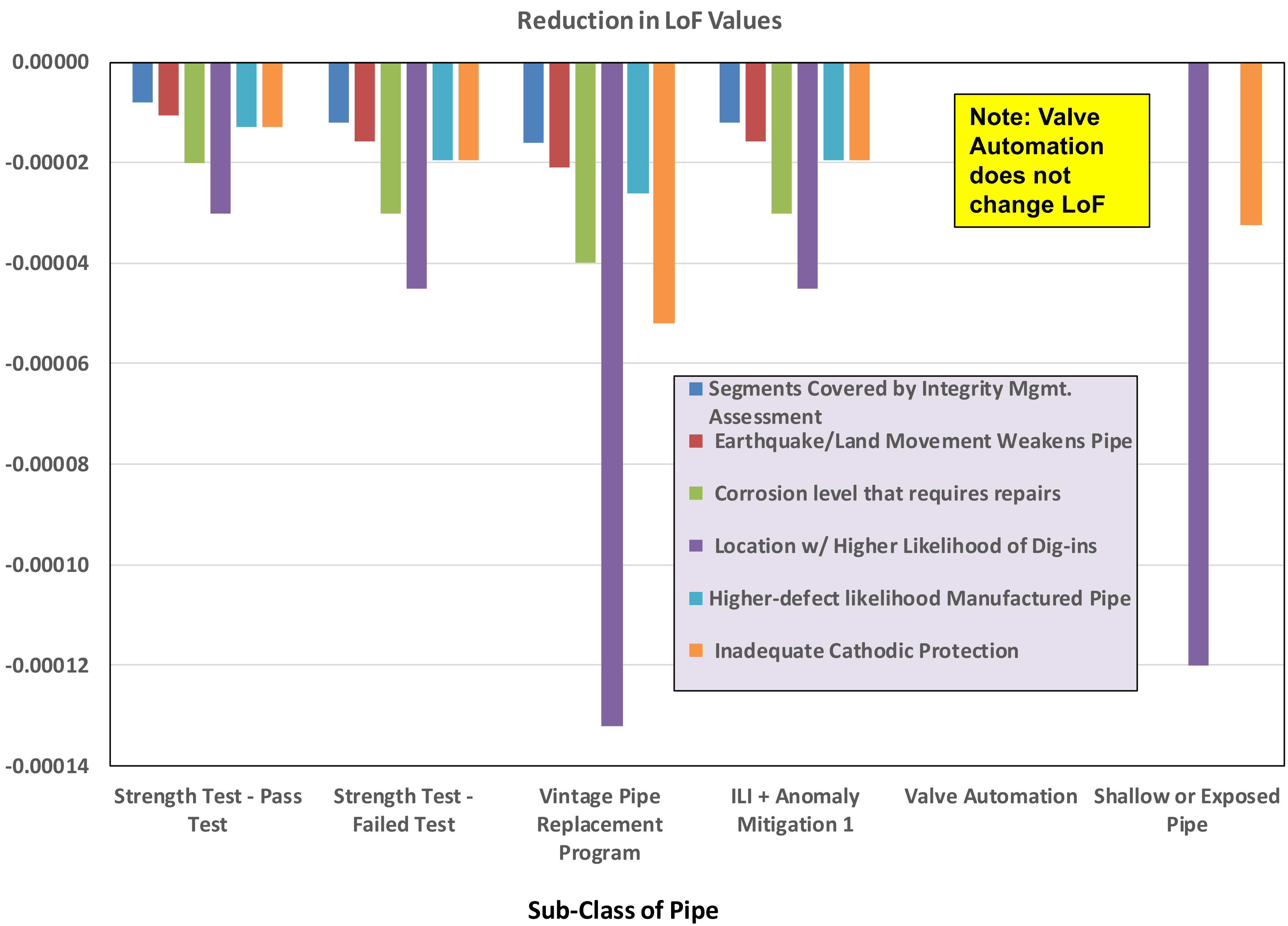
PG&E High Pressure Gas Pipeline Dynamic & Static Analysis: Post-Mitigation hazard rate multipliers

Mitigation	Post-Mitigation Parameters				
	HR_0	T	D	Location Multiplier	Cath. Prot. Mult
Strength Test - Pass Test	0.80	1.00	1.00	1.00	1.00
Strength Test - Failed Test+mitigation	0.70	1.50	1.50	1.00	1.00
Vintage Pipe Replacement Program	0.60	1.00	1.00	0.20	0.33
ILI + Anamoly Mitigation 1	0.70	2.00	2.00	1.00	1.00
Valve Automation	1.00	1.00	1.00	1.00	1.00
Shallow or Exposed Pipe	1.00	1.00	1.00	0.20	0.50

Examples

1. Replacing pipe reduces the base hazard rate for this type of pipe by 40% (hence the 0.60 HR_0 multiplier)
2. ILI/anomaly mitigation doubles the time for the base hazard rate to increase, from 30 years to 60 years

PG&E High Pressure Gas Pipeline Static Analysis



PG&E CoF Estimates, Static & Dynamic Analysis

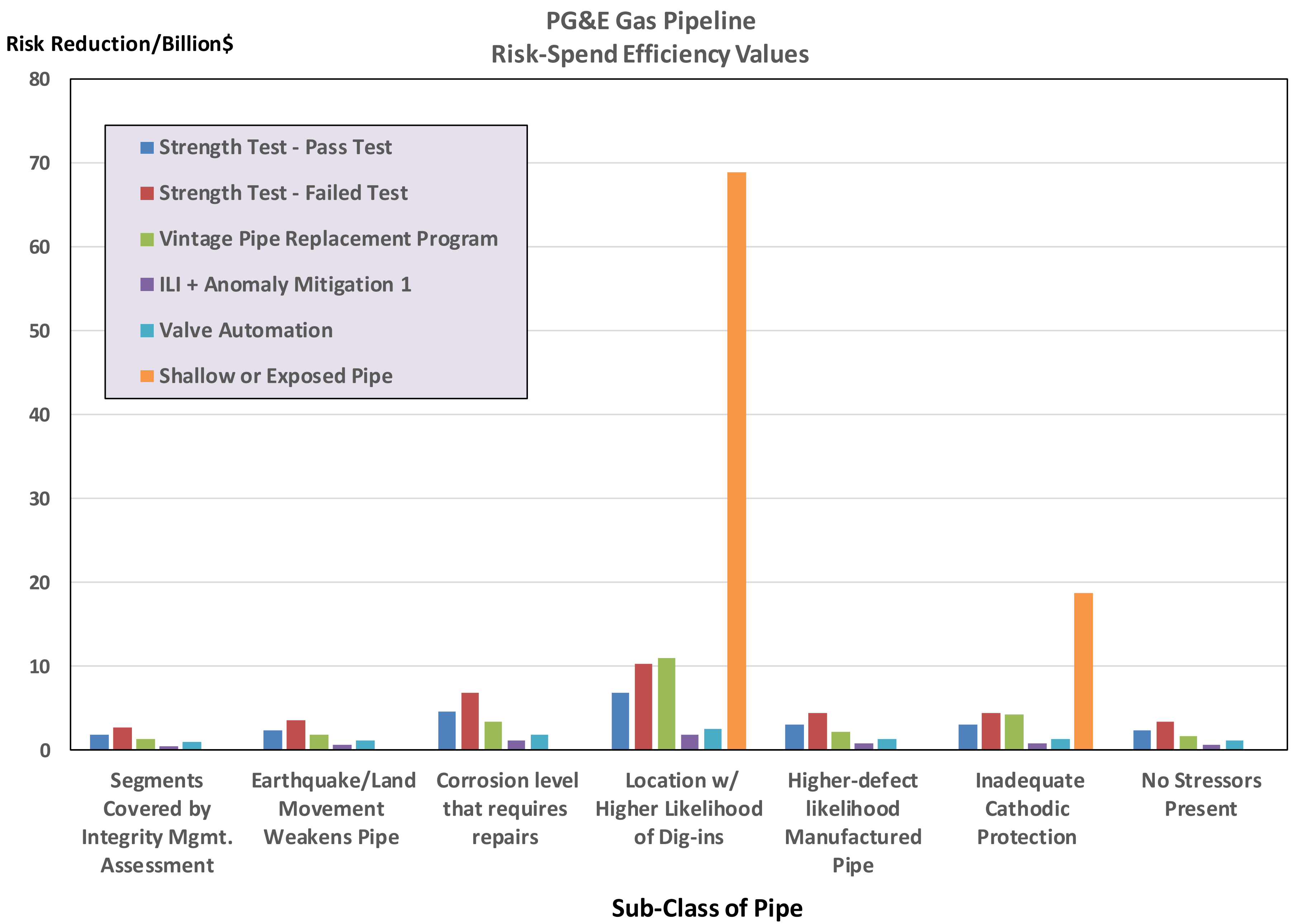
Attribute	Pre-Mitigation Levels Given Failure (percentiles)			Post-Mitigation Levels Given Failure (percentiles)		
MITIGATION: Strength Test - Pass Test						
	10th	Expected Value	90th	10th	Expected Value	90th
		Natural Units			**Natural Units**	
Safety						
Death		1.33			1.33	
S. Injury		6.666			6.666	
M. Injury		6.666			6.666	
Financial		$8,658,926			$8,658,926	
Environment						
Non-Sensitive Area		4.00			4.00	
Sensitive Area		15.00			15.00	
Customers Losing Service		24,574			24,574	
Customer Satisfaction		35.90%			35.90%	
Corporate Image		Negative			Negative	
		Scaled Units			**Scaled Units**	
Safety						
Death		1.330			1.330	
S. Injury		0.667			0.667	
M. Injury		0.067			0.067	
Financial		0.866			0.866	
Environment						
Non-Sensitive Area		2.250			2.250	
Sensitive Area		83.666			83.666	
Customer Loss of Service		2.457			2.457	
Customer Satisfaction		53.974			53.974	
Corporate Image		100.000			100.000	

Ex: Rupture expected to result in 1.33 deaths

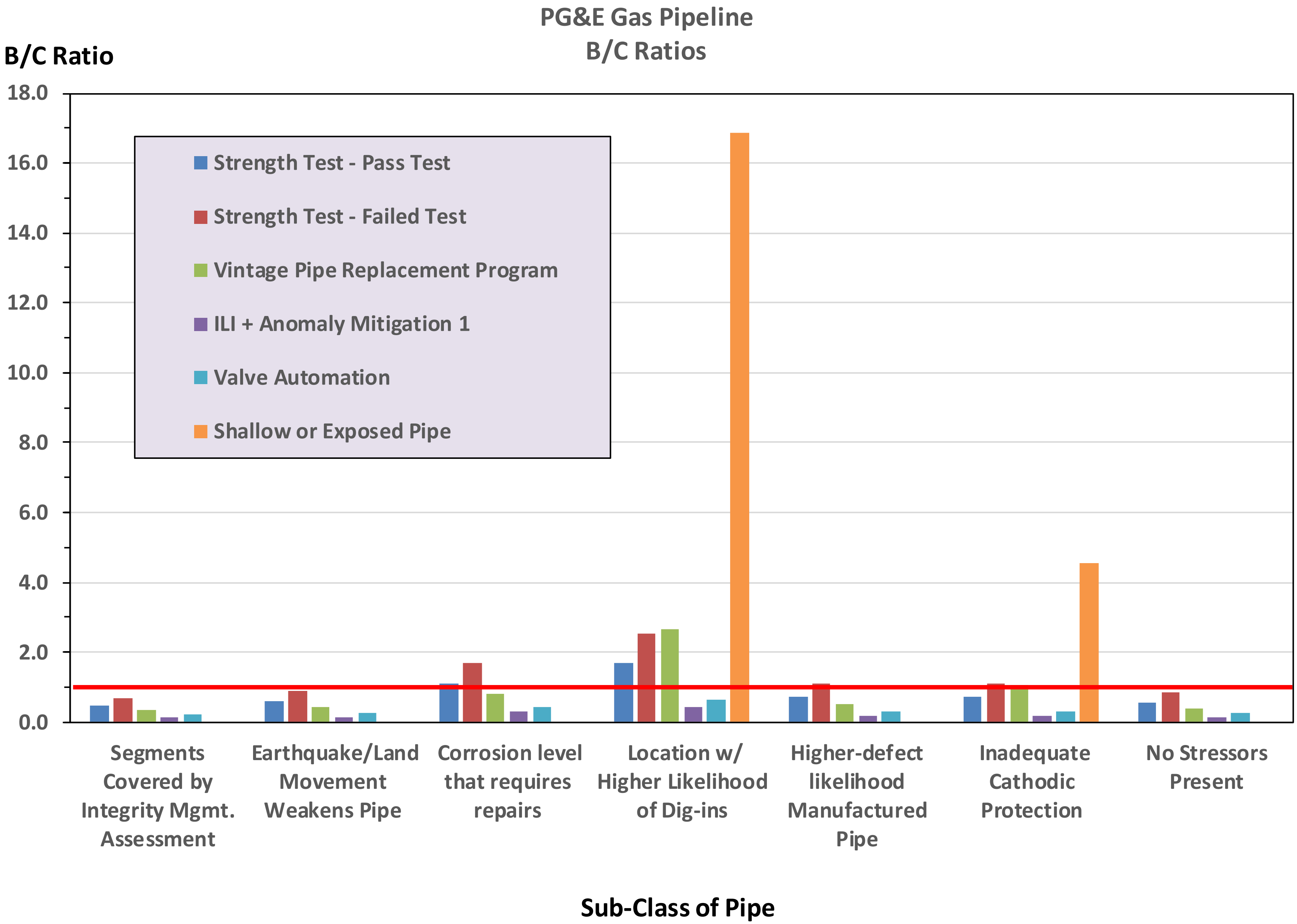
PG&E High Pressure Gas Pipeline, Static & Dynamic Analysis: MAVF Values

Attribute	Attribute Weight	Pre-Mitigation Expected Value Given Failure	Post-Mitigation Expected Value Given Failure	Pre-Mitigation Expected Value Given No Failure	Post-Mitigation Expected Value Given No Failure
MITIGATION: Shallow Exposed Pipe					
Safety					
Death	0.1636	1.3300	1.3300	0.000	0.0000
S. Injury	0.1636	0.6666	0.6666	0.000	0.0000
M. Injury	0.0818	0.0667	0.0667	0.000	0.0000
Financial	0.0409	0.8659	0.8659	0.000	0.0000
Environment					
Non-Sensitive Area	0.0123	2.2500	2.2500	0.000	0.0000
Sensitive Area	0.1227	83.6660	83.6660	0.000	0.0000
Customer Loss of Service	0.0409	2.4574	2.4574	0.000	0.0000
Customer Satisfaction	0.0409	53.9744	53.9744	35.897	35.8974
Corporate Image	0.0041	100.0000	100.0000	25.000	25.0000
MAVF Values		**13.37753**	**13.37753**	**1.57040**	**1.57040**
MITIGATION: Valve Automation					
Safety					
Death	0.1636	1.3300	1.3167	0.000	0.0000
S. Injury	0.1636	0.6666	0.6333	0.000	0.0000
M. Injury	0.0818	0.0667	0.0633	0.000	0.0000
Financial	0.0409	0.8659	0.7793	0.000	0.0000
Environment					
Non-Sensitive Area	0.0123	2.2500	2.2500	0.000	0.0000
Sensitive Area	0.1227	83.6660	67.0820	0.000	0.0000
Customer Loss of Service	0.0409	2.4574	2.3345	0.000	0.0000
Customer Satisfaction	0.0409	53.9744	65.4872	35.897	35.8974
Corporate Image	0.0041	100.0000	100.0000	25.000	25.0000
MAVF Values		**13.37753**	**11.79714**	**1.57040**	**1.57040**

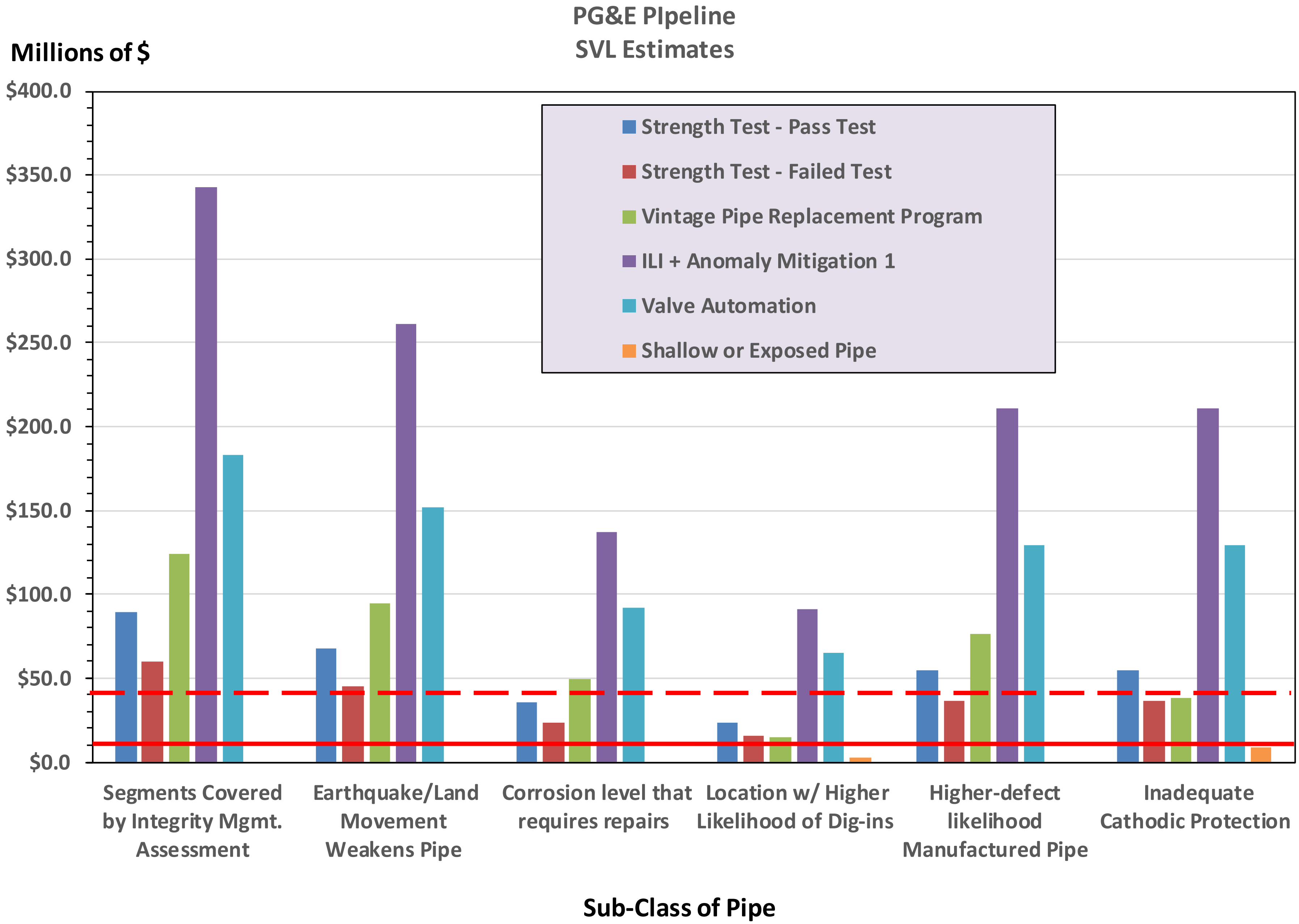
PG&E High Pressure Gas Pipeline Static Analysis: RSE



PG&E High Pressure Gas Pipeline Static Analysis: B/C Ratios



PG&E High Pressure Gas Pipeline Static Analysis: Implied SVL



Dynamic Analysis of PG&E High Pressure Pipeline

- State dependent optimal policy: (age, failure history)
- Optimal Policy compared with run-to-failure
- Value of Condition Testing (details next slide)

COMPARISON TABLE

	OPTIMAL POLICY	USER POLICY	COST SAVINGS
Total PV Cost ($000)	$3,175,297	$6,878,617	$3,703,320
PV Non-Failure Cost ($000)	$1,067,530	$787,626	-$279,905
PV Failure Cost ($000)	$2,107,767	$6,090,991	$3,983,225

VALUE OF TESTING COMPARISON

	NO TEST	WITH TEST	COST SAVINGS
Total PV Cost ($000)	$3,181,497	$3,175,297	$6,200

OPTIMAL POLICY

Age	No Failures	1 Failure	2+ Failures
0	No Action	Rejuvenate	Rejuvenate
1	No Action	Rejuvenate	Rejuvenate
2	No Action	Rejuvenate	Rejuvenate
3	No Action	Rejuvenate	Rejuvenate
4	No Action	Rejuvenate	Rejuvenate
5	No Action	Rejuvenate	Rejuvenate
6	No Action	Rejuvenate	Rejuvenate
7	No Action	Rejuvenate	Rejuvenate
8	No Action	Rejuvenate	Rejuvenate
9	No Action	Rejuvenate	Rejuvenate
10	No Action	Rejuvenate	Rejuvenate
11	No Action	Rejuvenate	Rejuvenate
12	No Action	Rejuvenate	Rejuvenate
13	No Action	Rejuvenate	Rejuvenate
14	No Action	Rejuvenate	Rejuvenate
15	No Action	Rejuvenate	Rejuvenate
16	Test	Rejuvenate	Rejuvenate
17	No Action	Rejuvenate	Rejuvenate
18	No Action	Rejuvenate	Rejuvenate
19	No Action	Rejuvenate	Rejuvenate
20	Test	Rejuvenate	Rejuvenate
21	Rejuvenate	Rejuvenate	Rejuvenate
22	Rejuvenate	Rejuvenate	Rejuvenate
23	No Action	Rejuvenate	Rejuvenate
24	Test	Rejuvenate	Rejuvenate
25	Rejuvenate	Rejuvenate	Rejuvenate
26	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
27	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
28	Test	STRENGTH TEST	STRENGTH TEST
29	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
30	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
31	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
32	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
33	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
34	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
35	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
36	Test	STRENGTH TEST	STRENGTH TEST
37	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
38	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
39	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
40	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST

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Dynamic Analysis of PG&E High Pressure Pipeline (cont'd)

Effect of Testing (4-yr interval)

	OPTIMAL POLICY WITH NO TESTING		
Age	No Failures	1 Failure	2+ Failures
0	No Action	STRENGTH TEST	STRENGTH TEST
1	No Action	STRENGTH TEST	STRENGTH TEST
2	No Action	STRENGTH TEST	STRENGTH TEST
3	No Action	STRENGTH TEST	STRENGTH TEST
4	No Action	STRENGTH TEST	STRENGTH TEST
5	No Action	STRENGTH TEST	STRENGTH TEST
6	No Action	STRENGTH TEST	STRENGTH TEST
7	No Action	STRENGTH TEST	STRENGTH TEST
8	No Action	STRENGTH TEST	STRENGTH TEST
9	No Action	STRENGTH TEST	STRENGTH TEST
10	No Action	STRENGTH TEST	STRENGTH TEST
11	No Action	STRENGTH TEST	STRENGTH TEST
12	No Action	STRENGTH TEST	STRENGTH TEST
13	No Action	STRENGTH TEST	STRENGTH TEST
14	No Action	STRENGTH TEST	STRENGTH TEST
15	No Action	STRENGTH TEST	STRENGTH TEST
16	No Action	STRENGTH TEST	STRENGTH TEST
17	No Action	STRENGTH TEST	STRENGTH TEST
18	No Action	STRENGTH TEST	STRENGTH TEST
19	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
20	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
21	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
22	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
23	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
24	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
25	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
26	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
27	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
28	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
29	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
30	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
31	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
32	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
33	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
34	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
35	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
36	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
37	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
38	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
39	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
40	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST

	OPTIMAL POLICY WITH TESTING		
Age	No Failures	1 Failure	2+ Failures
0	No Action	Rejuvenate	Rejuvenate
1	No Action	Rejuvenate	Rejuvenate
2	No Action	Rejuvenate	Rejuvenate
3	No Action	Rejuvenate	Rejuvenate
4	No Action	Rejuvenate	Rejuvenate
5	No Action	Rejuvenate	Rejuvenate
6	No Action	Rejuvenate	Rejuvenate
7	No Action	Rejuvenate	Rejuvenate
8	No Action	Rejuvenate	Rejuvenate
9	No Action	Rejuvenate	Rejuvenate
10	No Action	Rejuvenate	Rejuvenate
11	No Action	Rejuvenate	Rejuvenate
12	No Action	Rejuvenate	Rejuvenate
13	No Action	Rejuvenate	Rejuvenate
14	No Action	Rejuvenate	Rejuvenate
15	No Action	Rejuvenate	Rejuvenate
16	Test	Rejuvenate	Rejuvenate
17	No Action	Rejuvenate	Rejuvenate
18	No Action	Rejuvenate	Rejuvenate
19	No Action	Rejuvenate	Rejuvenate
20	Test	Rejuvenate	Rejuvenate
21	Rejuvenate	Rejuvenate	Rejuvenate
22	Rejuvenate	Rejuvenate	Rejuvenate
23	No Action	Rejuvenate	Rejuvenate
24	Test	Rejuvenate	Rejuvenate
25	Rejuvenate	Rejuvenate	Rejuvenate
26	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
27	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
28	Test	STRENGTH TEST	STRENGTH TEST
29	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
30	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
31	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
32	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
33	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
34	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
35	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
36	Test	STRENGTH TEST	STRENGTH TEST
37	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
38	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
39	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
40	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST

		TEST OUTCOME			
Age	Failures	"Condition 1"	"Condition 2"	"Condition 3"	"Condition 4"
16	0	Eff Age: 10	Rejuvenate	STRENGTH TEST	STRENGTH TEST
20	0	Eff Age: 10	Eff Age: 23	STRENGTH TEST	STRENGTH TEST
24	0	Eff Age: 10	Rejuvenate	STRENGTH TEST	STRENGTH TEST
28	0	Eff Age: 11	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
36	0	Eff Age: 27	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST

Reclassify in Lower Risk Class
Reclassify in Higher Risk Class

CONTINENTAL ECONOMICS VMN Group, LLC

Dynamic Analysis of PG&E High Pressure Pipeline (cont'd)

Effect of Testing (2-yr interval)

OPTIMAL POLICY WITH NO TESTING

Age	No Failures	1 Failure	2+ Failures
0	No Action	STRENGTH TEST	STRENGTH TEST
1	No Action	STRENGTH TEST	STRENGTH TEST
2	No Action	STRENGTH TEST	STRENGTH TEST
3	No Action	STRENGTH TEST	STRENGTH TEST
4	No Action	STRENGTH TEST	STRENGTH TEST
5	No Action	STRENGTH TEST	STRENGTH TEST
6	No Action	STRENGTH TEST	STRENGTH TEST
7	No Action	STRENGTH TEST	STRENGTH TEST
8	No Action	STRENGTH TEST	STRENGTH TEST
9	No Action	STRENGTH TEST	STRENGTH TEST
10	No Action	STRENGTH TEST	STRENGTH TEST
11	No Action	STRENGTH TEST	STRENGTH TEST
12	No Action	STRENGTH TEST	STRENGTH TEST
13	No Action	STRENGTH TEST	STRENGTH TEST
14	No Action	STRENGTH TEST	STRENGTH TEST
15	No Action	STRENGTH TEST	STRENGTH TEST
16	No Action	STRENGTH TEST	STRENGTH TEST
17	No Action	STRENGTH TEST	STRENGTH TEST
18	No Action	STRENGTH TEST	STRENGTH TEST
19	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
20	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
21	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
22	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
23	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
24	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
25	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
26	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
27	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
28	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
29	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
30	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
31	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
32	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
33	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
34	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
35	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
36	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
37	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
38	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
39	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
40	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST

OPTIMAL POLICY WITH TESTING

Age	No Failures	1 Failure	2+ Failures
0	No Action	Rejuvenate	Rejuvenate
1	No Action	Rejuvenate	Rejuvenate
2	No Action	Rejuvenate	Rejuvenate
3	No Action	Rejuvenate	Rejuvenate
4	No Action	Rejuvenate	Rejuvenate
5	No Action	Rejuvenate	Rejuvenate
6	No Action	Rejuvenate	Rejuvenate
7	No Action	Rejuvenate	Rejuvenate
8	No Action	Rejuvenate	Rejuvenate
9	No Action	Rejuvenate	Rejuvenate
10	No Action	Rejuvenate	Rejuvenate
11	No Action	Rejuvenate	Rejuvenate
12	No Action	Rejuvenate	Rejuvenate
13	No Action	Rejuvenate	Rejuvenate
14	No Action	Rejuvenate	Rejuvenate
15	No Action	Rejuvenate	Rejuvenate
16	Test	Rejuvenate	Rejuvenate
17	No Action	Rejuvenate	Rejuvenate
18	Test	Rejuvenate	Rejuvenate
19	No Action	Rejuvenate	Rejuvenate
20	Test	Rejuvenate	Rejuvenate
21	No Action	Rejuvenate	Rejuvenate
22	Test	Rejuvenate	Rejuvenate
23	No Action	Rejuvenate	Rejuvenate
24	Test	Rejuvenate	Rejuvenate
25	Rejuvenate	Rejuvenate	Rejuvenate
26	Test	STRENGTH TEST	STRENGTH TEST
27	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
28	Test	STRENGTH TEST	STRENGTH TEST
29	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
30	Test	STRENGTH TEST	STRENGTH TEST
31	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
32	Test	STRENGTH TEST	STRENGTH TEST
33	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
34	Test	STRENGTH TEST	STRENGTH TEST
35	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
36	Test	STRENGTH TEST	STRENGTH TEST
37	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
38	Test	STRENGTH TEST	STRENGTH TEST
39	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
40	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST

TEST OUTCOME

Age	Failures	"Condition 1"	"Condition 2"	"Condition 3"	"Condition 4"
16	0	Eff Age: 10	Rejuvenate	STRENGTH TEST	STRENGTH TEST
18	0	Eff Age: 10	Rejuvenate	STRENGTH TEST	STRENGTH TEST
20	0	Eff Age: 10	Eff Age: 23	STRENGTH TEST	STRENGTH TEST
22	0	Eff Age: 10	Eff Age: 23	STRENGTH TEST	STRENGTH TEST
24	0	Eff Age: 10	Rejuvenate	STRENGTH TEST	STRENGTH TEST
26	0	Eff Age: 10	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
28	0	Eff Age: 11	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
30	0	Eff Age: 11	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
32	0	Eff Age: 21	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
34	0	Eff Age: 25	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
36	0	Eff Age: 27	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST
38	0	Eff Age: 29	STRENGTH TEST	STRENGTH TEST	STRENGTH TEST

Reclassify in Lower Risk Class
Reclassify in Higher Risk Class

VALUE OF TESTING COMPARISON

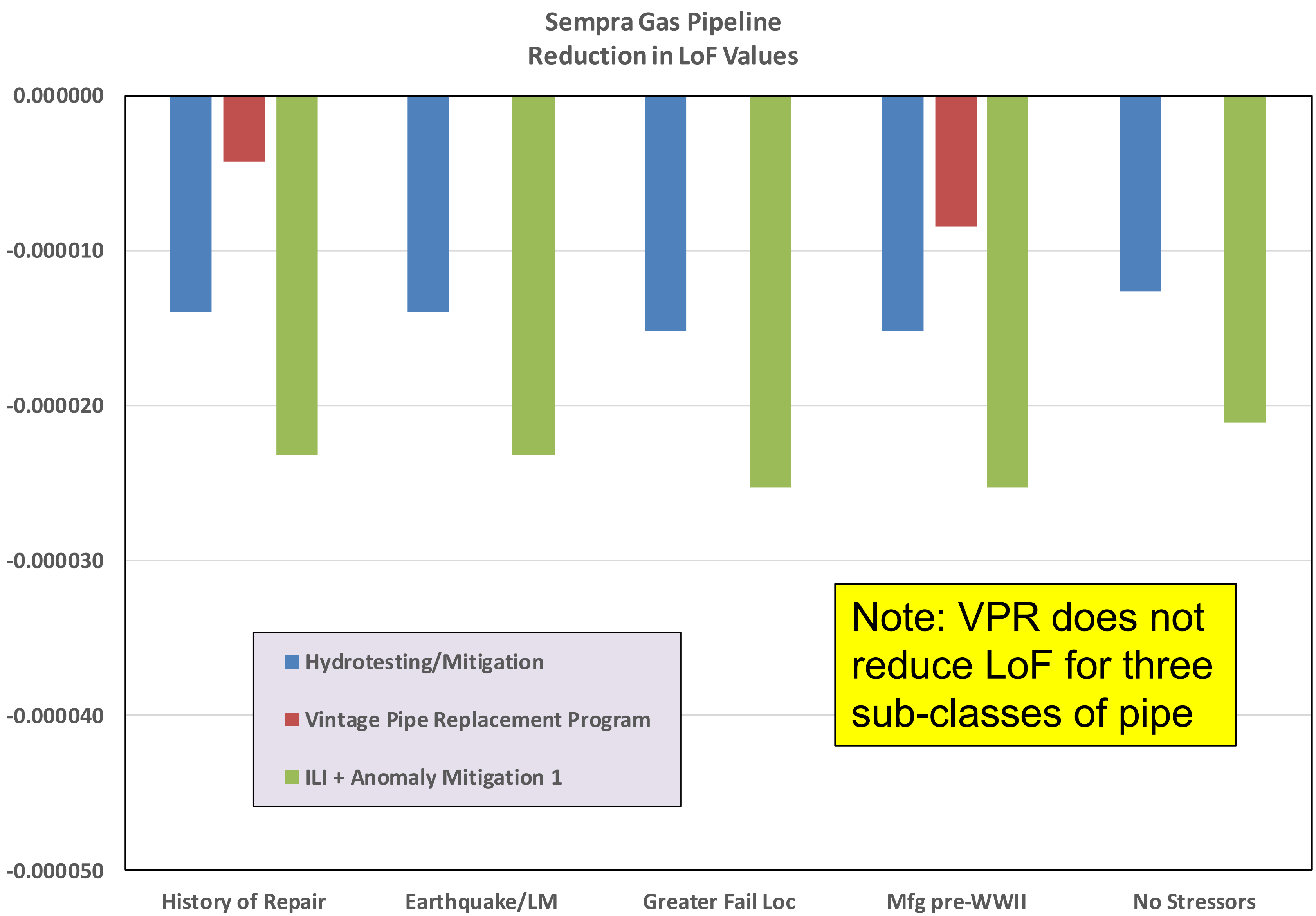
	NO TEST	WITH TEST	COST SAVINGS
Total PV Cost (000's)	$3,181,497	$3,172,861	$8,636

CONTINENTAL ECONOMICS VMN Group, LLC

Sempra High Pressure Gas Pipeline

- Failure Event: Defined broadly to include pipe that is still operable but incapable of satisfactory performance. Excludes dig-ins, which Sempra treats separately
- Mitigation alternatives provided for analysis:
  - (1) hydrotesting/mitigation; (2) ILI/mitigation; (3) vintage pipe replacement
- Base Hazard Rate Multiplier: Probability of failure of a segment: 0.00047
- Outside Events:
  - Overpressure event (1 every 12.5 years)
  - Catastrophic earthquake (1 every 33.3 years)

Sempra post-mitigation reduction in LoF values, Static & Dynamic Analysis



Sempra gas pipeline static & dynamic analysis – CoF Values

Attribute	Pre-Mitigation Attribute Levels Given Failure			Post-Mitigation Attribute Levels Given Failure		
MITIGATION: Hydro Test						
	10th	50th	90th	10th	50th	90th
		Natural Units			**Natural Units**	
Safety						
Death		0.02			0.02	
S. Injury		0.1			0.1	
M. Injury		0.4			0.4	
Lost Time		0			0	
Financial		$1,000,000			$1,000,000	
Environment						
Non-Sensitive Area		2.00			2.00	
Sensitive Area		2.00			2.00	
Compliance		4.00			4.00	
Customers Losing Service		50,000			50,000	
Customer Satisfaction		58.00%			58.00%	
Workforce Planning						
Employee Satisfaction		90.00%			90.00%	
Workforce Capability		Neutral			Neutral	
Corporate Image		Neutral			Neutral	
		Scaled Units			**Scaled Units**	
Safety						
Death		0.020			0.020	
S. Injury		0.010			0.010	
M. Injury		0.004			0.004	
Lost Time		0.000			0.000	
Financial		0.100			0.100	
Environment						
Non-Sensitive Area		0.250			0.250	
Sensitive Area		22.361			22.361	
Compliance		0.100			0.100	
Customers Losing Service		5.000			5.000	
Customer Satisfaction		25.641			25.641	
Workforce Planning						
Employee Satisfaction		10.000			10.000	
Workforce Capability		33.000			33.000	
Corporate Image		25.000			25.000	

Sempra gas pipeline static & dynamic analysis – MAVF values

Attribute	Attribute Weight	Pre-Mitigation Expected Value	Post-Mitigation Expected Value	No Failure MAVF Values
MITIGATION: ILI + Anomaly Mitigation				
Safety				
Death	0.1636	0.0200	0.0200	0.0000
S. Injury	0.1636	0.0100	0.0100	0.0000
M. Injury	0.0818	0.0040	0.0040	0.0000
Lost Time	0.0082	0.0000	0.0000	0.0000
Financial	0.0409	0.1000	0.1000	0.0000
Environment				
Non-Sensitive Area	0.0123	0.2500	0.2500	0.0000
Sensitive Area	0.1227	22.3607	22.3607	0.0000
Compliance	0.1636	0.1000	0.1000	0.0000
Customers Losing Service	0.0409	5.0000	5.0000	0.0000
Customer Satisfaction	0.0409	25.6410	25.6410	23.0769
Workforce Planning				
Employee Satisfaction	0.0246	10.0000	10.0000	10.0000
Workforce Capability	0.0049	33.0000	33.0000	33.0000
Corporate Image	0.0041	25.0000	25.0000	25.0000
MAVF Values		**4.53601**	**4.53601**	**1.45434**

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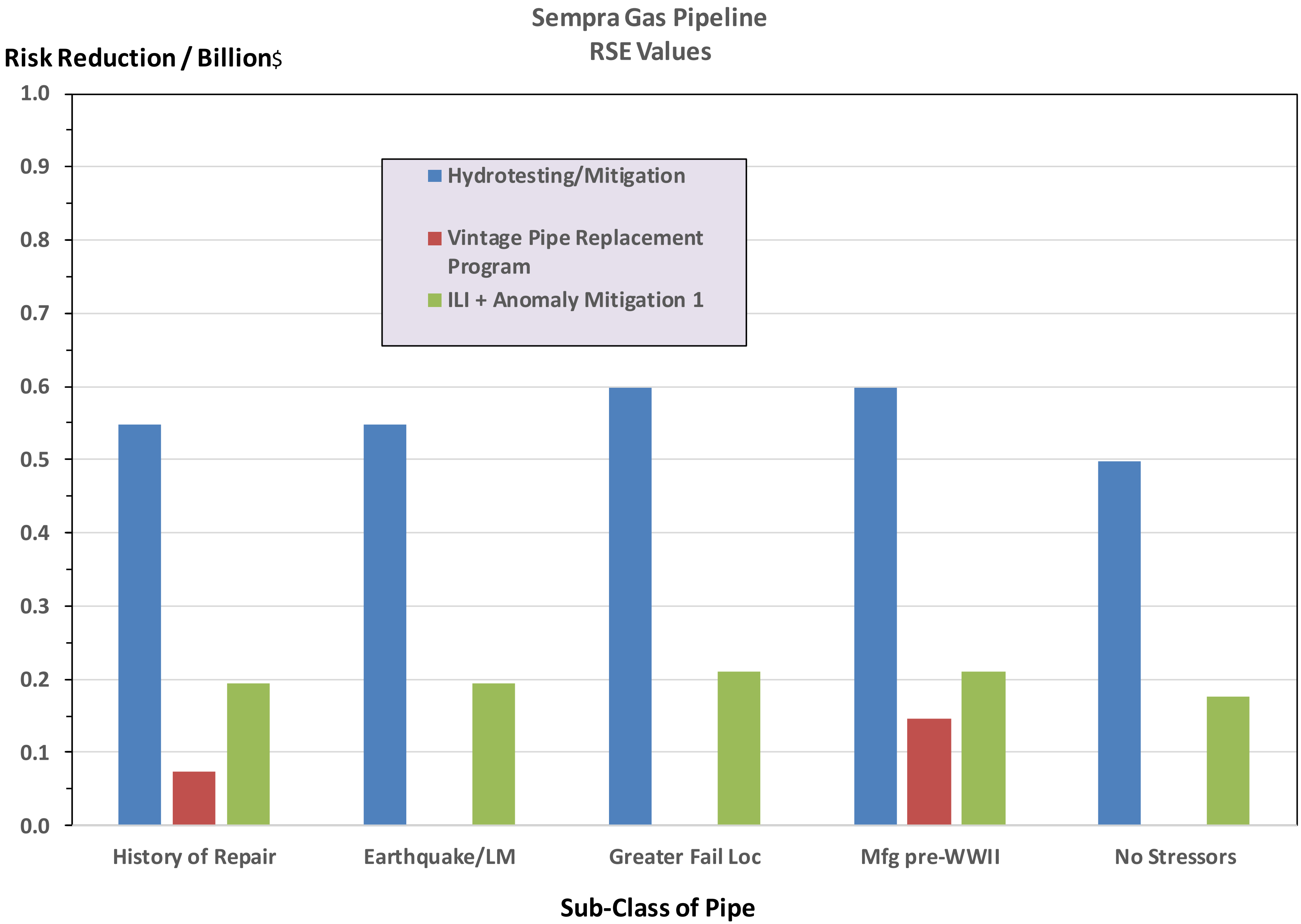
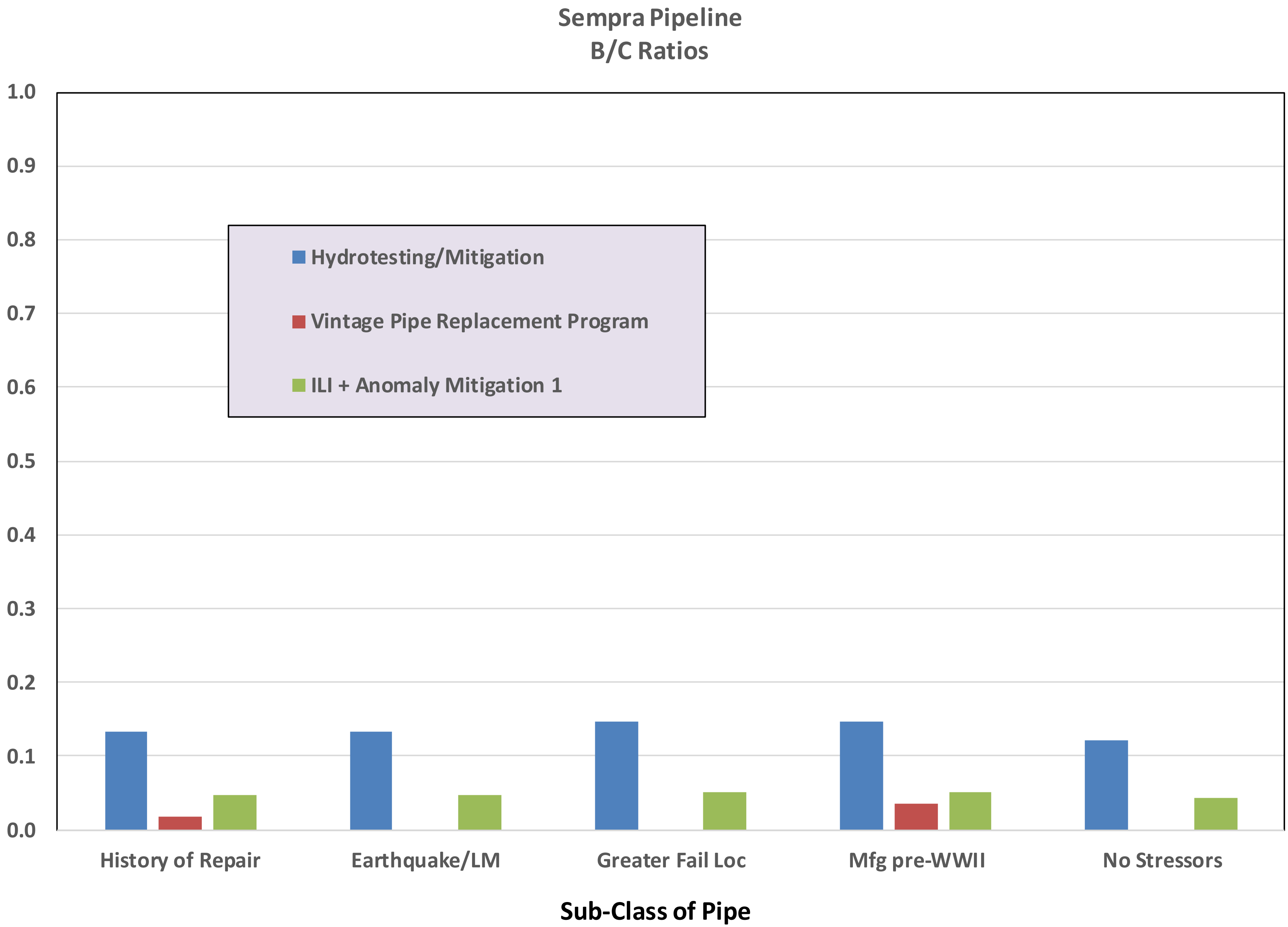
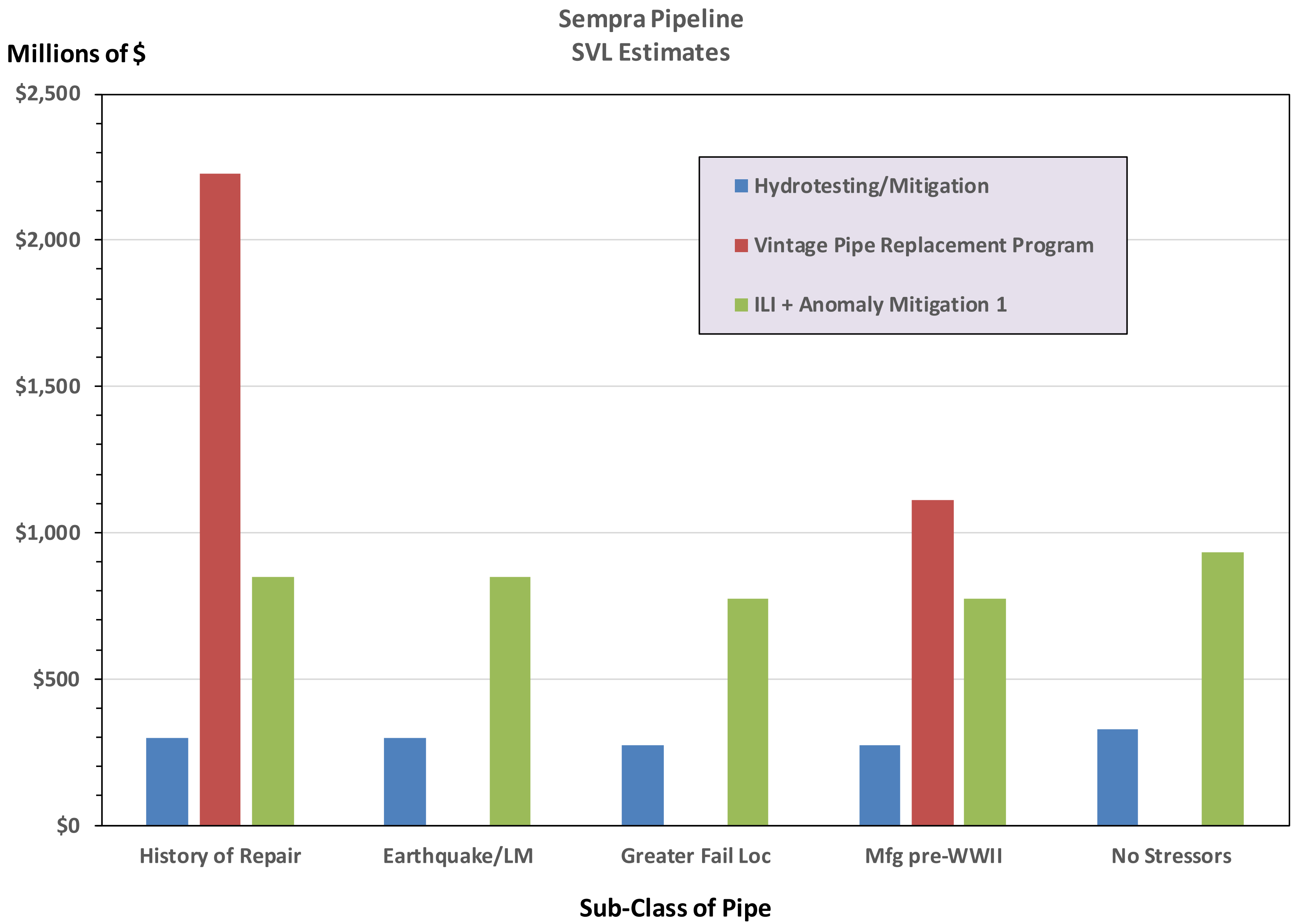
Sempra gas pipeline static analysis- RSE Values



Sempra gas pipeline static analysis- B/C Ratios



Sempra gas pipeline static analysis- SVL Values



SCE Overhead Conductor Analysis

- Failure event: Wire down
- Mitigation alternatives provided for analysis:
  - (1) reconductoring, (2) aerial cable, (3) tree wire, (4) undergrounding
- Base Hazard rate
  - SCE informed us that all conductors have different base hazard rates, which depend on their specific characteristics
  - Length, percent of small conductor, previous fault events, etc.
- To address this, we estimated a regression model to predict number of WD events/year on each circuit. (SCE reviewed regression and OK'd)
  - Determined changes in LoF for each of 3,800+ circuits
  - Determined corresponding RSE, B/C ratio, and SVL values for each circuit

SCE Overhead Conductor Analysis (cont.)

- In addition to Static Analysis, performed dynamic analysis of different circuits to illustrate that part of methodology
  - Assumed circuit condition deteriorates over time, increasing the likelihood of WD events
  - Examined the value of testing circuit condition
- Dynamic Analysis identifies the optimal policy for each circuit
  - Maximizes expected present value of risk reduction subject to constraints

SCE OH Conductor Static & Dynamic Analysis – Calculation of LoF (example for circuit 12)

Base Hazard Rate Variable	Regression Coefficients	
Total miles of OH Conductor	0.009822	
Circuit Breaker Operations	0.010310	
Fault Duty	0.000188	
OH DIMP Notifications	0.029233	
Small as Pct of Total Length	0.162386	
Enter Circuit Number to be Analyzed:	**12**	OK
Circuit Region	[San Joaquin Region]	
Total miles of OH Conductor	27.830	
Circuit Breaker Operations	23.000	
Fault Duty	193.200	Data taken from "Calculations" worksheet
OH DIMP Notifications	0.000	Length of Small Conductor (feet)
Small as Pct of Total Length	49.12%	72,182
Pre-Mitigation Expected Events per Year	***0.390145***	Based on regression parameters
Pre-Mitigation Base Hazard Rate (HR_0)	**0.323041**	Converted to probability w/ poisson

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SCE OH Conductor Static & Dynamic Analysis – Mitigations and Hazard Rate Changes

Mitigation	SCE Reductions in Base Hazard Rate	Post-Mitigation Hazard Rate (Circuit 12)
1. Reconductoring	47%	0.1712120
2. Aerial Cable	57%	0.1389078
3. Tree Wire	47%	0.1712120
4. Undergrounding	100%	0.0000000

Post-mitigation hazard rates based on pre-mitigation hazard rate of 0.323 shown on previous slide. Each circuit different

SCE OH Conductor Static & Dynamic Analysis – Pre-Mitigation CoF

Outcome	Atttribute	Probability	Natural Units	Scaled Units	Attribute Weights	Pr x Weight x Units
Injury	Safety - Death	0.0007271	2	2.00	0.1636	0.00024
	Financial	0.0007271	$16,500,000	1.65	0.0409	0.00005
Wildfire	Environmental (non-sen	0.0000155	19.974	90.00	0.0123	0.00002
	Safety - Death	0.0000155	2	2.00	0.1636	0.00001
	Financial	0.0000155	$1,650,000,000	165.00	0.0409	0.00010
Property Damage	Financial	0.0024722	$165,000	0.0165	0.0409	0.00000
	Safety (Serious Injury)	0.0001454	4	0.4000	0.1636	0.00001
Outage	Reliability	0.3550088	0.132	0.0220	0.0409	0.00032
Freeway/Road Closure	Financial	0.0714791	$165,000	0.0165	0.0409	0.00005
				Pre-Mitigation CoF:		**0.00079**

Mitigation	Reductions in Probability of Specific Consequence				
	Injury	**Wildfire**	**Property Damage**	**Outage**	**Road Closure**
1. Reconductoring	0%	0%	0%	0%	0%
2. Aerial Cable	75%	50%	50%	0%	0%
3. Tree Wire	60%	40%	40%	0%	0%
4. Undergrounding	100%	100%	100%	100%	100%

SCE OH Conductor Static & Dynamic Analysis – Post Mitigation CoF (Circuit 12)

Outcome	Atttribute	Mitigation			
		Reconductoring	Aerial Cable	Tree Wire	Undergrounding
Injury	Safety - Death	0.000238	0.000059	0.000095	0.000000
	Financial	0.000049	0.000012	0.000020	0.000000
Wildfire	Environmental (non-sen	0.000017	0.000009	0.000010	0.000000
	Safety - Death	0.000005	0.000003	0.000003	0.000000
	Financial	0.000105	0.000052	0.000063	0.000000
Property Damage	Financial	0.000002	0.000001	0.000001	0.000000
	Safety (Serious Injury)	0.000010	0.000005	0.000006	0.000000
Outage	Reliability	0.000319	0.000319	0.000319	0.000000
Freeway/Road Closure	Financial	0.000048	0.000048	0.000048	0.000000
Post-Mitigation CoF:		**0.000793**	**0.000508**	**0.000565**	**0.000000**

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Static Analysis: Top 5 Circuits with Highest RSE Values, B/C Ratios

Risk Spend Efficiency Values (Risk Reduction per $Billion Spent)				
Circuit Number	Reconductoring	Aerial Cable	Tree Wire	Undergrounding
2018	570.6219	476.0000	456.4975	468.1261
3047	530.2269	442.3034	424.1815	434.9869
3075	462.3360	385.6703	369.8688	379.2906
249	461.0740	384.6176	368.8592	258.8063
2363	455.1671	379.6902	364.1336	255.4906

Bemefit-Cost Ratios				
Circuit Number	Reconductoring	Aerial Cable	Tree Wire	Undergrounding
2018	139.516362	116.381430	111.613090	114.456263
3047	129.639819	108.142639	103.711856	106.353757
3075	113.040580	94.295924	90.432464	92.736094
249	112.732033	94.038542	90.185627	63.277821
2363	111.287787	92.833784	89.030230	62.467148

Static Analysis: 5 Circuits with Lowest RSE values, B/C Ratios

Risk Spend Efficiency Values (Risk Reduction per $Billion Spent)				
Circuit Number	Reconductoring	Aerial Cable	Tree Wire	Undergrounding
2675	0.0444	0.0370	0.0355	0.0249
2009	0.0389	0.0324	0.0311	0.0218
592	0.0341	0.0285	0.0273	0.0191
1867	0.0260	0.0217	0.0208	0.0180
2299	0.0186	0.0155	0.0149	0.0104

Benefit/Cost Ratios				
Circuit Number	Reconductoring	Aerial Cable	Tree Wire	Undergrounding
2675	0.010857	0.009057	0.008686	0.006094
2009	0.009509	0.007932	0.007607	0.005338
592	0.008341	0.006958	0.006673	0.004682
1867	0.006367	0.005311	0.005094	0.004399
2299	0.004550	0.003795	0.003640	0.002554

Dynamic Analysis of SCE Overhead Conductor

- Circuit 12, San Joaquin Region
- State dependent optimal policy: (age, failure history)
- Optimal Policy compared with run-to-failure
- Value of Condition Testing (details next slide)

COMPARISON TABLE

	OPTIMAL POLICY	USER POLICY	COST SAVINGS
Total PV Cost (000's)	$14,144	$18,911	$4,767

VALUE OF TESTING COMPARISON

	NO TEST	WITH TEST	COST SAVINGS
Total PV Cost (000's)	$15,336	$14,144	$1,192

OPTIMAL POLICY

Age	No Failures	1 Failure	2+ Failures
0	No Action	No Action	No Action
1	No Action	No Action	No Action
2	No Action	No Action	No Action
3	No Action	No Action	No Action
4	No Action	No Action	No Action
5	No Action	No Action	No Action
6	No Action	No Action	No Action
7	No Action	No Action	No Action
8	No Action	No Action	No Action
9	No Action	No Action	No Action
10	No Action	No Action	No Action
11	No Action	No Action	No Action
12	No Action	No Action	No Action
13	No Action	No Action	No Action
14	No Action	No Action	No Action
15	No Action	No Action	No Action
16	Test	Test	Test
17	No Action	No Action	No Action
18	No Action	No Action	No Action
19	No Action	No Action	No Action
20	Test	Test	Test
21	No Action	No Action	No Action
22	No Action	No Action	No Action
23	No Action	No Action	No Action
24	Test	Test	Test
25	No Action	No Action	Rejuvenate
26	No Action	No Action	Rejuvenate
27	No Action	No Action	Rejuvenate
28	Test	Test	Rejuvenate
29	No Action	No Action	Rejuvenate
30	No Action	No Action	Rejuvenate
31	No Action	No Action	Rejuvenate
32	Test	Test	Test
33	No Action	No Action	Rejuvenate
34	No Action	No Action	Rejuvenate
35	No Action	No Action	Rejuvenate
36	Test	Test	Test
37	No Action	No Action	Rejuvenate
38	No Action	No Action	Rejuvenate
39	No Action	No Action	Rejuvenate
40	Test	Test	Test

Dynamic Analysis of SCE Overhead Conductor --Circuit 12 (cont'd)

Effect of Testing (4-yr interval)

OPTIMAL POLICY WITH NO TESTING

Age	No Failures	1 Failure	2+ Failures
0	No Action	No Action	No Action
1	No Action	No Action	No Action
2	No Action	No Action	No Action
3	No Action	No Action	No Action
4	No Action	No Action	No Action
5	No Action	No Action	No Action
6	No Action	No Action	No Action
7	No Action	No Action	No Action
8	No Action	No Action	No Action
9	No Action	No Action	No Action
10	No Action	No Action	No Action
11	No Action	No Action	No Action
12	No Action	No Action	No Action
13	No Action	No Action	No Action
14	No Action	No Action	No Action
15	No Action	No Action	No Action
16	No Action	No Action	No Action
17	No Action	No Action	No Action
18	No Action	No Action	No Action
19	No Action	No Action	No Action
20	No Action	No Action	No Action
21	No Action	No Action	No Action
22	No Action	No Action	No Action
23	No Action	No Action	Rejuvenate
24	No Action	No Action	Rejuvenate
25	No Action	No Action	Rejuvenate
26	No Action	No Action	Rejuvenate
27	No Action	No Action	Rejuvenate
28	No Action	No Action	Rejuvenate
29	No Action	No Action	Rejuvenate
30	No Action	No Action	Rejuvenate
31	No Action	No Action	Rejuvenate
32	No Action	No Action	Rejuvenate
33	No Action	No Action	Rejuvenate
34	No Action	No Action	Rejuvenate
35	No Action	Rejuvenate	Rejuvenate
36	No Action	Rejuvenate	Rejuvenate
37	No Action	Rejuvenate	Rejuvenate
38	No Action	No Action	Rejuvenate
39	No Action	No Action	Rejuvenate
40	No Action	No Action	Rejuvenate

OPTIMAL POLICY WITH TESTING

Age	No Failures	1 Failure	2+ Failures
0	No Action	No Action	No Action
1	No Action	No Action	No Action
2	No Action	No Action	No Action
3	No Action	No Action	No Action
4	No Action	No Action	No Action
5	No Action	No Action	No Action
6	No Action	No Action	No Action
7	No Action	No Action	No Action
8	No Action	No Action	No Action
9	No Action	No Action	No Action
10	No Action	No Action	No Action
11	No Action	No Action	No Action
12	No Action	No Action	No Action
13	No Action	No Action	No Action
14	No Action	No Action	No Action
15	No Action	No Action	No Action
16	Test	Test	Test
17	No Action	No Action	No Action
18	No Action	No Action	No Action
19	No Action	No Action	No Action
20	Test	Test	Test
21	No Action	No Action	No Action
22	No Action	No Action	No Action
23	No Action	No Action	No Action
24	Test	Test	Test
25	No Action	No Action	Rejuvenate
26	No Action	No Action	Rejuvenate
27	No Action	No Action	Rejuvenate
28	Test	Test	Rejuvenate
29	No Action	No Action	Rejuvenate
30	No Action	No Action	Rejuvenate
31	No Action	No Action	Rejuvenate
32	Test	Test	Test
33	No Action	No Action	Rejuvenate
34	No Action	No Action	Rejuvenate
35	No Action	No Action	Rejuvenate
36	Test	Test	Test
37	No Action	No Action	Rejuvenate
38	No Action	No Action	Rejuvenate
39	No Action	No Action	Rejuvenate
40	Test	Test	Test

TEST OUTCOME

Age	Failures	"Condition 1"	"Condition 2"	"Condition 3"	"Condition 4"
16	0	Eff Age: 11	Eff Age: 14	Eff Age: 23	Eff Age: 36
16	1	Eff Age: 12	Eff Age: 18	Eff Age: 24	Rejuvenate
16	2	Eff Age: 14	Eff Age: 17	Rejuvenate	Rejuvenate
20	0	Eff Age: 11	Eff Age: 19	Eff Age: 29	Eff Age: 40
20	1	Eff Age: 16	Eff Age: 21	Eff Age: 28	Rejuvenate
20	2	Eff Age: 17	Eff Age: 20	Rejuvenate	Rejuvenate
24	0	Eff Age: 11	Eff Age: 23	Eff Age: 33	Eff Age: 40
24	1	Eff Age: 19	Eff Age: 24	Eff Age: 32	Eff Age: 40
24	2	Eff Age: 19	Eff Age: 23	Rejuvenate	Rejuvenate
28	0	Eff Age: 11	Eff Age: 27	Eff Age: 37	Eff Age: 40
28	1	Eff Age: 21	Eff Age: 27	Eff Age: 36	Eff Age: 40
32	0	Eff Age: 16	Eff Age: 31	Eff Age: 40	Eff Age: 40
32	1	Eff Age: 23	Eff Age: 30	Eff Age: 39	Eff Age: 40
32	2	Eff Age: 24	Rejuvenate	Rejuvenate	Rejuvenate
36	0	Eff Age: 20	Eff Age: 33	Eff Age: 40	Eff Age: 40
36	1	Eff Age: 26	Eff Age: 32	Eff Age: 40	Eff Age: 40
36	2	Eff Age: 26	Rejuvenate	Rejuvenate	Rejuvenate
40	0	Eff Age: 24	Eff Age: 36	Eff Age: 40	Eff Age: 40
40	1	Eff Age: 28	Eff Age: 35	Eff Age: 40	Eff Age: 40
40	2	Rejuvenate	Rejuvenate	Rejuvenate	Rejuvenate

Reclassify in Lower Risk Class
Reclassify in Higher Risk Class

CONTINENTAL ECONOMICS

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Dynamic Analysis of SCE Overhead Conductor

- Circuit 1259, Orange Region
- State dependent optimal policy: (age, failure history)
- Optimal Policy compared with run-to-failure
- Value of Condition Testing (details next slide)

COMPARISON TABLE

	OPTIMAL POLICY	USER POLICY	COST SAVINGS
Total PV Cost (000's)	$2,039	$2,654	$615

	NO TEST	WITH TEST	COST SAVINGS
Total PV Cost (000's)	$2,039	$2,039	$.424

OPTIMAL POLICY

Age	No Failures	1 Failure	2+ Failures
0	No Action	No Action	No Action
1	No Action	No Action	No Action
2	No Action	No Action	No Action
3	No Action	No Action	No Action
4	No Action	No Action	No Action
5	No Action	No Action	No Action
6	No Action	No Action	No Action
7	No Action	No Action	No Action
8	No Action	No Action	No Action
9	No Action	No Action	No Action
10	No Action	No Action	Reconductor
11	No Action	No Action	Reconductor
12	Test	Test	Reconductor
13	No Action	No Action	Reconductor
14	No Action	No Action	Reconductor
15	No Action	No Action	Reconductor
16	Test	Test	Reconductor
17	No Action	Reconductor	Reconductor
18	No Action	Reconductor	Reconductor
19	No Action	Reconductor	Reconductor
20	Test	Reconductor	Reconductor
21	Reconductor	Reconductor	Reconductor
22	Reconductor	Reconductor	Reconductor
23	No Action	Reconductor	Reconductor
24	Test	Reconductor	Reconductor
25	Reconductor	Reconductor	Reconductor
26	Reconductor	Reconductor	Reconductor
27	Reconductor	Reconductor	Reconductor
28	Test	Reconductor	Reconductor
29	Reconductor	Reconductor	Reconductor
30	Reconductor	Reconductor	Reconductor
31	Reconductor	Reconductor	Reconductor
32	Test	Reconductor	Reconductor
33	Reconductor	Reconductor	Reconductor
34	Reconductor	Reconductor	Reconductor
35	Reconductor	Reconductor	Reconductor
36	Test	Reconductor	Reconductor
37	Reconductor	Reconductor	Reconductor
38	Reconductor	Reconductor	Reconductor
39	Reconductor	Reconductor	Reconductor
40	Reconductor	Reconductor	Reconductor

Dynamic Analysis of SCE Overhead Conductor --Circuit 1259 (cont'd)

Effect of Testing (4-yr interval)

OPTIMAL POLICY WITH NO TESTING

Age	No Failures	1 Failure	2+ Failures
0	No Action	No Action	No Action
1	No Action	No Action	No Action
2	No Action	No Action	No Action
3	No Action	No Action	No Action
4	No Action	No Action	No Action
5	No Action	No Action	No Action
6	No Action	No Action	No Action
7	No Action	No Action	No Action
8	No Action	No Action	No Action
9	No Action	No Action	No Action
10	No Action	No Action	Reconductor
11	No Action	No Action	Reconductor
12	No Action	No Action	Reconductor
13	No Action	No Action	Reconductor
14	No Action	No Action	Reconductor
15	No Action	No Action	Reconductor
16	No Action	Reconductor	Reconductor
17	No Action	Reconductor	Reconductor
18	No Action	Reconductor	Reconductor
19	No Action	Reconductor	Reconductor
20	Reconductor	Reconductor	Reconductor
21	Reconductor	Reconductor	Reconductor
22	Reconductor	Reconductor	Reconductor
23	Reconductor	Reconductor	Reconductor
24	Reconductor	Reconductor	Reconductor
25	Reconductor	Reconductor	Reconductor
26	Reconductor	Reconductor	Reconductor
27	Reconductor	Reconductor	Reconductor
28	Reconductor	Reconductor	Reconductor
29	Reconductor	Reconductor	Reconductor
30	Reconductor	Reconductor	Reconductor
31	Reconductor	Reconductor	Reconductor
32	Reconductor	Reconductor	Reconductor
33	Reconductor	Reconductor	Reconductor
34	Reconductor	Reconductor	Reconductor
35	Reconductor	Reconductor	Reconductor
36	Reconductor	Reconductor	Reconductor
37	Reconductor	Reconductor	Reconductor
38	Reconductor	Reconductor	Reconductor
39	Reconductor	Reconductor	Reconductor
40	Reconductor	Reconductor	Reconductor

OPTIMAL POLICY WITH TESTING

Age	No Failures	1 Failure	2+ Failures
0	No Action	No Action	No Action
1	No Action	No Action	No Action
2	No Action	No Action	No Action
3	No Action	No Action	No Action
4	No Action	No Action	No Action
5	No Action	No Action	No Action
6	No Action	No Action	No Action
7	No Action	No Action	No Action
8	No Action	No Action	No Action
9	No Action	No Action	No Action
10	No Action	No Action	Reconductor
11	No Action	No Action	Reconductor
12	Test	Test	Reconductor
13	No Action	No Action	Reconductor
14	No Action	No Action	Reconductor
15	No Action	No Action	Reconductor
16	Test	Test	Reconductor
17	No Action	Reconductor	Reconductor
18	No Action	Reconductor	Reconductor
19	No Action	Reconductor	Reconductor
20	Test	Reconductor	Reconductor
21	Reconductor	Reconductor	Reconductor
22	Reconductor	Reconductor	Reconductor
23	No Action	Reconductor	Reconductor
24	Test	Reconductor	Reconductor
25	Reconductor	Reconductor	Reconductor
26	Reconductor	Reconductor	Reconductor
27	Reconductor	Reconductor	Reconductor
28	Test	Reconductor	Reconductor
29	Reconductor	Reconductor	Reconductor
30	Reconductor	Reconductor	Reconductor
31	Reconductor	Reconductor	Reconductor
32	Test	Reconductor	Reconductor
33	Reconductor	Reconductor	Reconductor
34	Reconductor	Reconductor	Reconductor
35	Reconductor	Reconductor	Reconductor
36	Test	Reconductor	Reconductor
37	Reconductor	Reconductor	Reconductor
38	Reconductor	Reconductor	Reconductor
39	Reconductor	Reconductor	Reconductor
40	Reconductor	Reconductor	Reconductor

TEST OUTCOME

Age	Failures	"Condition 1"	"Condition 2"	"Condition 3"	"Condition 4"
12	0	Eff Age: 0	Eff Age: 11	Reconductor	Reconductor
12	1	Eff Age: 10	Reconductor	Reconductor	Reconductor
16	0	Eff Age: 11	Eff Age: 15	Reconductor	Reconductor
16	1	Eff Age: 12	Reconductor	Reconductor	Reconductor
20	0	Eff Age: 11	Reconductor	Reconductor	Reconductor
24	0	Eff Age: 11	Reconductor	Reconductor	Reconductor
28	0	Eff Age: 11	Reconductor	Reconductor	Reconductor
32	0	Eff Age: 17	Reconductor	Reconductor	Reconductor
36	0	Eff Age: 24	Reconductor	Reconductor	Reconductor

Reclassify in Lower Risk Class
Reclassify in Higher Risk Class

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Dynamic Analysis of SCE Overhead Conductor

- Circuit 152, Desert Region
- State dependent optimal policy: (age, failure history)
- Optimal Policy compared with run-to-failure
- Value of Condition Testing = 0

COMPARISON TABLE

	OPTIMAL POLICY	USER POLICY	COST SAVINGS
Total PV Cost (000's)	$2,211	$3,045	$834

VALUE OF TESTING COMPARISON

	NO TEST	WITH TEST	COST SAVINGS
Total PV Cost (000's)	$2,211	$2,211	$

OPTIMAL POLICY

Age	No Failures	1 Failure	2+ Failures
0	Tree Wire	Tree Wire	Tree Wire
1	Tree Wire	Tree Wire	Tree Wire
2	Tree Wire	Tree Wire	Tree Wire
3	Tree Wire	Tree Wire	Tree Wire
4	Tree Wire	Tree Wire	Tree Wire
5	Tree Wire	Tree Wire	Tree Wire
6	Tree Wire	Tree Wire	Tree Wire
7	Tree Wire	Tree Wire	Tree Wire
8	Tree Wire	Tree Wire	Tree Wire
9	Tree Wire	Tree Wire	Tree Wire
10	Tree Wire	Tree Wire	Tree Wire
11	Tree Wire	Tree Wire	Tree Wire
12	Tree Wire	Tree Wire	Tree Wire
13	Tree Wire	Tree Wire	Tree Wire
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Dynamic Analysis of SCE Overhead Conductor

- Circuit 3608, Desert Region
- State dependent optimal policy: (age, failure history)
- Optimal Policy compared with run-to-failure
- Value of Condition Testing = 0

COMPARISON TABLE

	OPTIMAL POLICY	USER POLICY	COST SAVINGS
Total PV Cost (000's)	$2,437	$3,425	$988

VALUE OF TESTING COMPARISON

	NO TEST	WITH TEST	COST SAVINGS
Total PV Cost (000's)	$2,437	$2,437	$

OPTIMAL POLICY

Age	No Failures	1 Failure	2+ Failures
0	Aerial Cable	Aerial Cable	Aerial Cable
1	Aerial Cable	Aerial Cable	Aerial Cable
2	Aerial Cable	Aerial Cable	Aerial Cable
3	Aerial Cable	Aerial Cable	Aerial Cable
4	Aerial Cable	Aerial Cable	Aerial Cable
5	Aerial Cable	Aerial Cable	Aerial Cable
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40	Aerial Cable	Aerial Cable	Aerial Cable

SDG&E Workplace Violence Problem

- Failure event: Shooting in the workplace, either by an SDG&E employee or an outside actor
  - Note: SDG&E JUA analysis does not differentiate between two actors
- Mitigation alternatives provided for analysis:
  - (i) active shooter training program; (ii) enhanced physical security in SDG&E offices
  - Note: SDG&E JUA analysis excludes (ii) and included an alternative of hiring security guards. (JIA not provided with this alternative)
- Base Hazard Rate
  - 1 WPV event committed by employees every 40 years
  - 1 WPV event committed by outside actors every 30 years

SDG&E WPV Analysis (hazard rates)

- Multipliers:
  - Dangerous location, past history of violence, poor performance evaluation

Item	SDGE Employees	External Actors	Overall
1. Frequency (Avg. WPV Events /year)	0.0250	0.0333	0.0583
Expected years per event	40.0	30.00	
Pre-Mitigation LoF	**0.024690**	**0.032784**	**0.056665**
2. Hazard Rate Multipliers			
a. Dangerous Location	1.10	1.50	
Percent of population affected	5.000%	0.010%	
b. Past History of Violence	2.00	2.00	
Percent of population affected	0.01%	0.38314%	
c. Poor Performance Evaluation	1.0001	n/a	
Percent of population affected	0.100%	n/a	
3. Populations	6,300	2,552,000	
Pre-Mitigation Base Hazard Rates (HR_0) per person	**0.000003948**	**0.000000013**	

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SDG&E WPV Analysis: CoF Values

Attribute	Pre-Mitigation Percentile Values			Post-Mitigation Percentile Values		
	10th	50th	90th	10th	50th	90th
		Natural Units			**Natural Units**	
Safety						
Death	2	15	25	1	14	24
S. Injury	15	25	35	14	25	34
M. Injury	25	35	45	25	34	44
Lost Time	30	40	50	29	39	49
Financial	$10,000,000	$20,000,000	$30,000,000	$9,000,000	$19,000,000	$29,000,000
		Scaled Units			**Scaled Units**	
Safety						
Death	2.000	15.000	25.000	1.000	14.000	24.000
S. Injury	1.500	2.500	3.500	1.400	2.500	3.400
M. Injury	0.250	0.350	0.450	0.250	0.340	0.440
Lost Time	3.000	4.000	5.000	2.900	3.900	4.900
Financial	1.000	2.000	3.000	0.900	1.900	2.900

Note the 10-50-90 values for deaths and injuries, pre- and post-mitigation.

SDG&E JUA analysis: 0.02 deaths (page 84 of 87)

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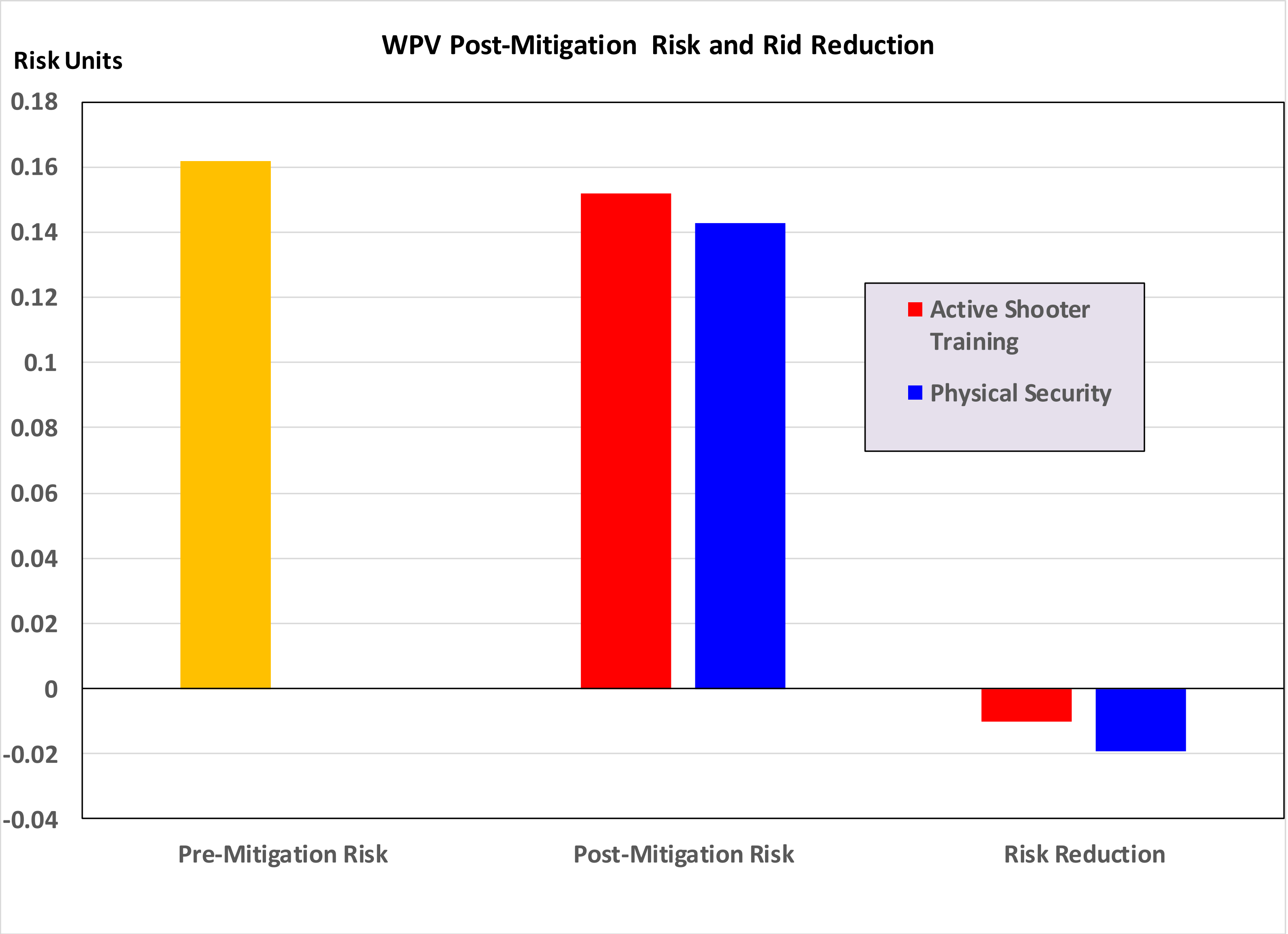
SDG&E WPV Analysis: Risk Levels



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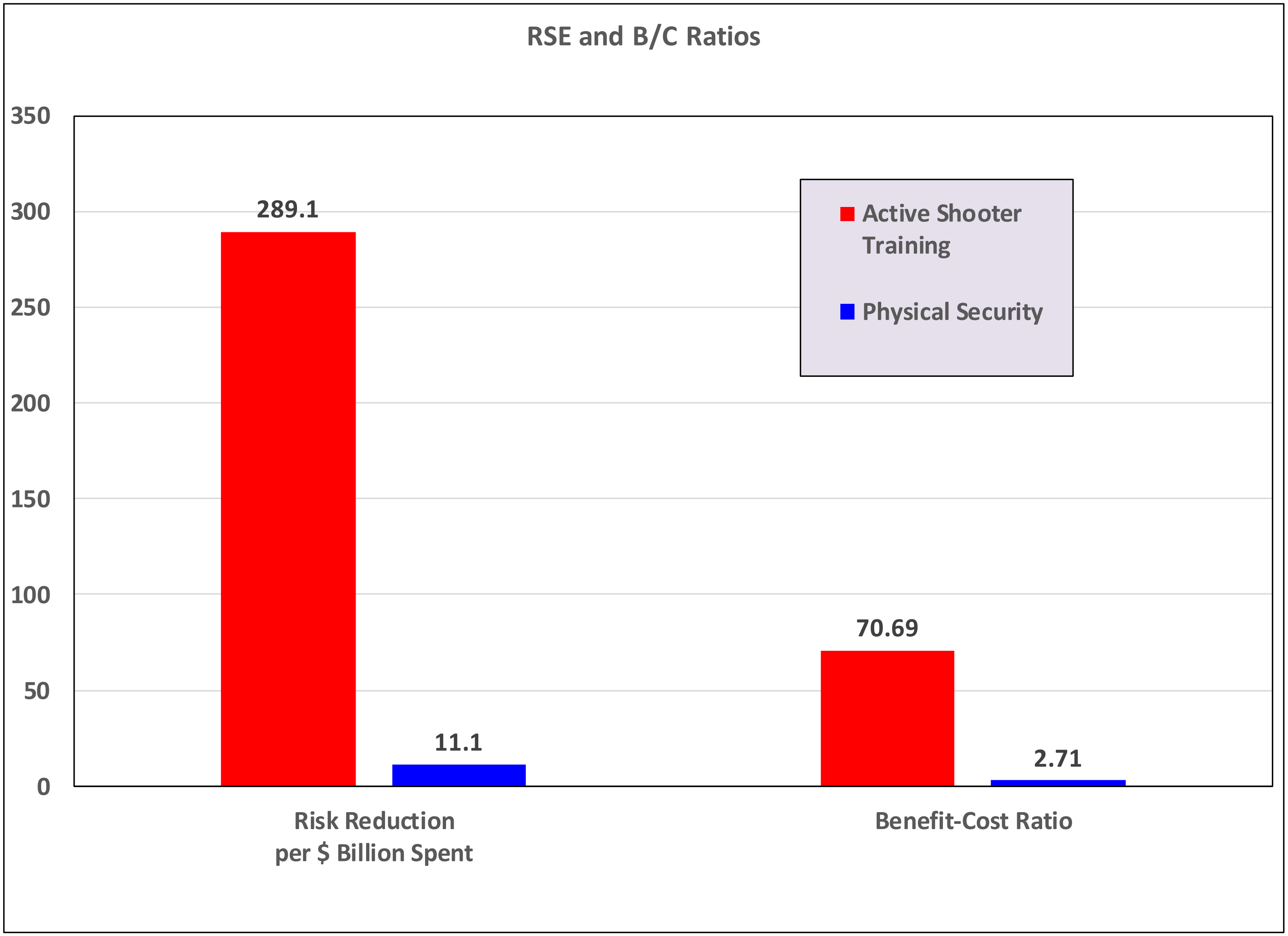
SDG&E WPV Analysis: RSE and B/C Ratios



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Effectiveness of Active Shooter Training

- Initial analysis assumed 100% of employees trained immediately and all training is 100% effective forever
  - Employees do not "forget" their training
- Evaluated alternative model acknowledging that training effectiveness generally degrades over time
  - New employees must be trained, other employees leave
  - Model determined "steady-state" fraction of fully trained employees

	Steady-State Fraction Trained	Risk Reduction per $ Billion Spent	Implied Benefit-Cost Ratio	SVL (Millions of $)
	18.2%	52.6	12.85	$3.11
	43.8%	126.5	30.93	$1.29
Base Case	58.9%	170.2	41.60	$0.96
→	**100.0%**	**289.1**	**70.69**	**$0.57**

PG&E Workforce Adequacy Problem

- Failure Event: inadequately trained field worker makes an error causing adverse consequences
- Mitigation Alternatives:
  - (i) portable technology access – to everyone, to crew leads/foremen, or for qualification status; (ii) 24/7 technical support desk; (iii) work scheduling (systematic stop); (iv) expanded use of qualification cards (electric field workers only)
- Base Hazard Rate:
  - 1 event per year committed by gas field workers
  - 2.62 events per year committed by electric field workers
  - Event frequency affected by (i) emergency response; (ii) tenure of worker (apprentice, journeyman, or experienced); and skill level
  - Note: PG&E JUA does not include skill level breakdown/impacts

PG&E Workforce Adequacy: Hazard Rate

Item	Gas Field Employees	Probability	Electric Field Employees	Probability
Expected number of events per employee per year	0.000328	**0.000328**	0.000813	**0.0008128**
2. Total Number of Employees	3,058		3,222	
3. Implied Number of Events / Yr	**1.0043**		**2.6200**	
4. Hazard Rate Multipliers				
a. Emergency Response	1.20		1.50	
Number of Emergency Response Events/Yr	**0.111**	**0.104919**	**0.289**	**0.251107**
Base Hazard Rate (HR_0)	**0.000322**	**0.000322**	**0.000722**	**0.000722**
		HR_0 Gas		**HR_0 Electric**

Gas field workers 20% more likely to make an error responding to an emergency;

Electric field workers 50% more likely to make an error responding to an emergency;

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PG&E Workforce Adequacy: CoF

Attribute	Pre-Mitigation Attribute Levels		
All Mitigations Have No Impact on Consequences	10th	50th **Natural Units**	90th
Safety			
Death	0.0010640	0.0083306	1.1312296
Serious Injury	0.0016978	0.0189000	0.5861307
Minor Injury	0.0016978	0.0189000	0.5861307
Lost Time	0.0271642	0.3023998	9.3780913
SAIDI	0.0225013	0.0412770	0.1201369
Customers Affected by Loss of Service	4500	8500	25000
Financial	$494,999.32	$760,299.28	$1,235,788.27
Environment			
Non-Sensitive Area			
Sensitive Area	5	8	11
Compliance	2	3	4
Customer Satisfaction	0	0	0

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PG&E Workforce Adequacy: MAVF

Attribute	Attribute Weight	Pre-Mitigation Expected Value	Post-Mitigation Expected Value
All Mitigations Have No Impact on Consequences			
Safety			
Death	0.1636	0.3447	0.3447
Serious Injury	0.1636	0.0185	0.0185
Minor Injury	0.0818	0.0018	0.0018
Lost Time	0.0082	0.2956	0.2956
SAIDI	0.0409	0.0099	0.0099
Customers Affected by Loss of Service	0.0409	1.2269	1.2269
Financial	0.0409	0.0824	0.0824
Environment			
Non-Sensitive Area			
Sensitive Area	0.1227	58.2896	58.2896
Compliance	0.1636	0.0344	0.0344
Customer Satisfaction			
MAVF Values		**7.27371**	**7.27371**

Note that the environmental attribute expected value accounts for over 98% of total MAVF.

Because 1 risk unit equivalent to **$244.5** million, EV of environmental damage is 0.1227 x 58.29 x $244.5 million = **$1.75 billion per incident**

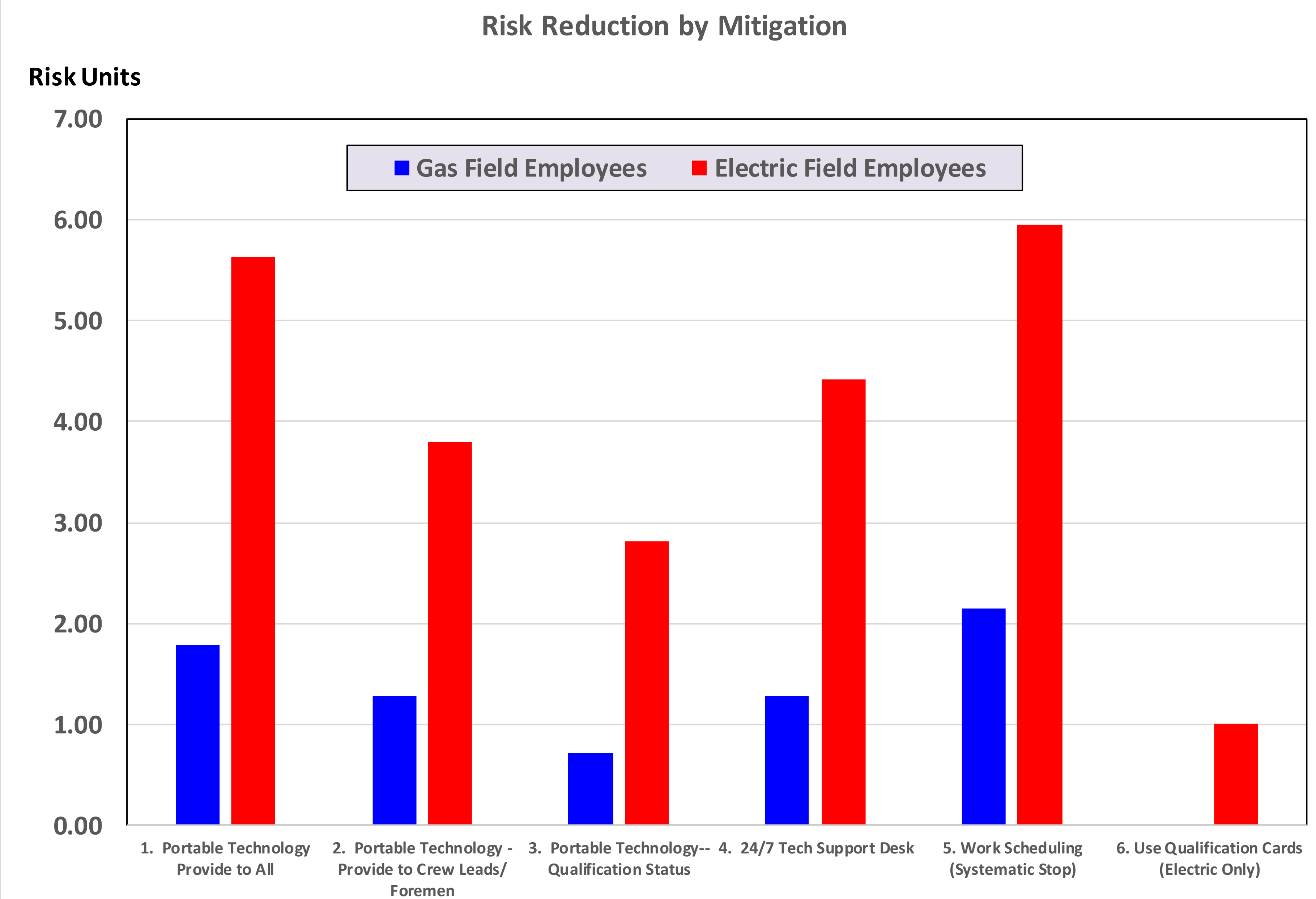
PGE JUA: $2,029

PG&E Workforce Adequacy: Skill Level Breakdown

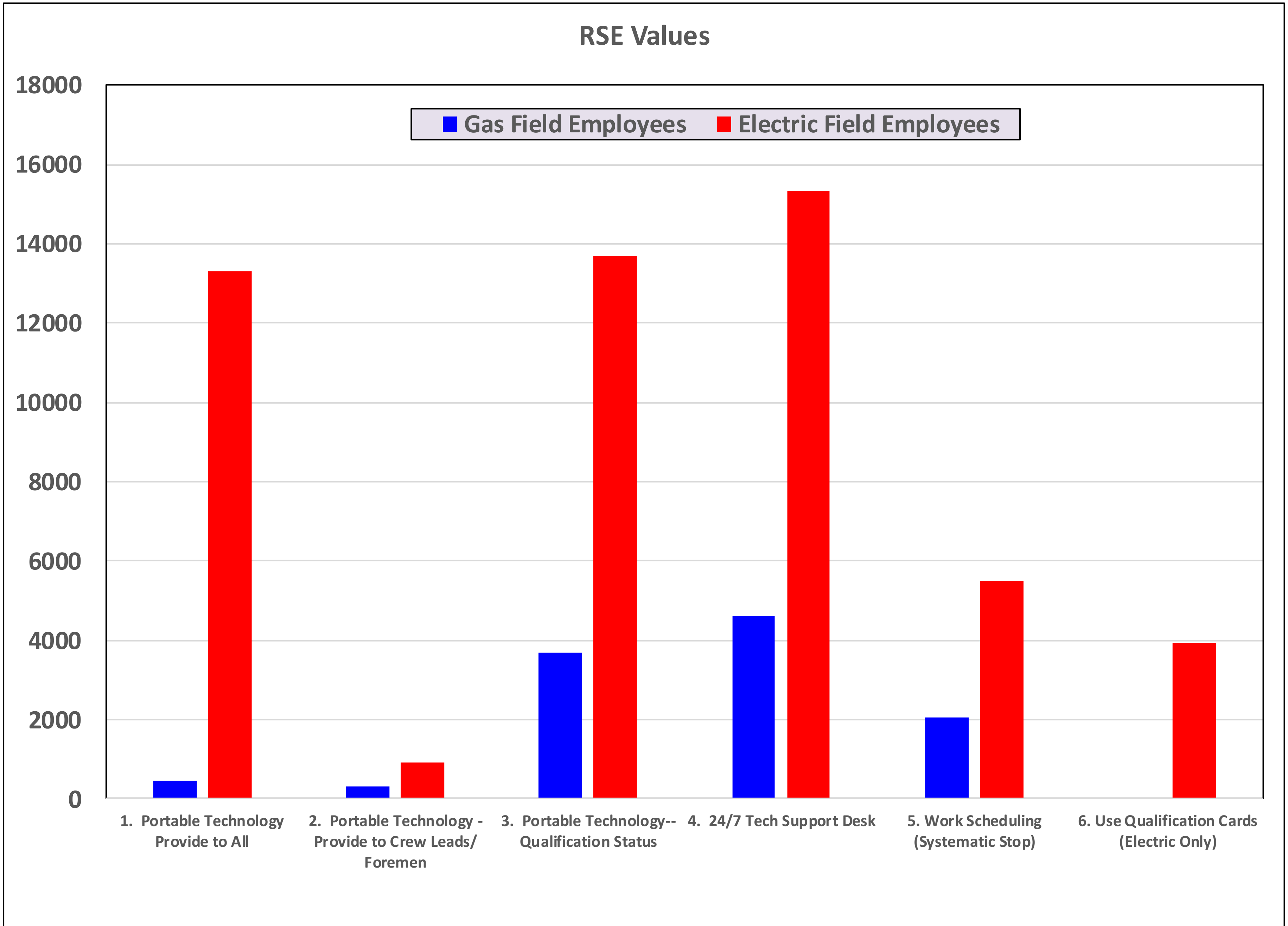
Gas Field Employees			
TENURE	SKILL < 85%	85% <= SKILL <= 95%	SKILL >95%
EXPERIENCED (E)	0.7%	4.2%	27.2%
JOURNEY (J)	1.1%	7.0%	45.6%
APPRENTICE (A)	0.2%	1.6%	12.4%

Electric Field Employees			
TENURE	SKILL < 85%	85% <= SKILL <= 95%	SKILL >95%
EXPERIENCED (E)	0.7%	12.1%	23.8%
JOURNEY (J)	1.0%	15.8%	31.1%
APPRENTICE (A)	0.9%	1.4%	13.3%

PG&E Risk Reduction Values, by Employee Group



PG&E RSE Values, by Employee Group



Summary of

Overall Test Drive Results-

Conclusions from the JIA Test Drive

(Day 2, Post-Lunch Session)

Validates the value of the JIA features endorsed on an interim basis in D.16-08-018 (pp. 90-94, 114), including:

- LoF based on Mathematical Probability - Uncertainty can be reflected in LoF by converting a range of frequencies into a probability using Poisson distribution
- Condition Dependent Hazard Rate: LoF should take into account observed behavior and condition of assets to give a more accurate measure of the LoF
- Continuous Consequence of Failure Scores - using a continuous 1-100 scale

Validation of JIA Features Endorsed by Commission (cont'd):

- Multi-Attribute Utility Functions – Utilities should calculate CoF using a properly designed MAUF (i.e., properly scaled and weighted to combine various consequences of a failure event into a single unit)
- Prioritization of Projects by Risk Reduction per Dollar Spent – an interim means to judge cost-effectiveness
- Enables longer term improvements, including:
  - Improved Data Collection – gives better understanding of data needs
  - Improved Hazard Rates – because long-lived assets change over time, utilities should take into account dynamic nature of assets

Demonstrates Usefulness for Both Asset-Based and Non-Asset Problems

- JIA successfully used for Workplace Violence and Skilled and Qualified Workforce Test Problems
  - JIA was asked to solve and solved more detailed problems than reflected in JUA test drives for WPV and Skilled/Qualified WF

JIA Test Drive Shows Benefits of a Bottom-up Methodology

- Different groups of assets can have different LoF and CoF values
  - E.g., All else being equal, corroded pipe more likely to fail than uncorroded
  - E.g., CoF for 12-inch pipe operating at 100 psi less than CoF on 34-inch pipe operating at 500 psi
- JIA separates assets into groups with similar LoF and CoF characteristics
  - CoF values can be described more accurately the more specific the asset group (example: probability distribution of consequences for 34-inch pipe rupture vs CoF probability distribution for all types of pipe)
  - Allows for more targeted optimization (dynamic) or cost-effectiveness (static)

Benefits of a Bottom-up Methodology (cont'd)

- SMEs can better identify factors affecting LoF for narrower classes of assets
  - Easier to answer questions such as "how much more likely is a corroded segment pipe to rupture vs. uncorroded" vs. "how will probability distribution of the number of rupture events change for the entire inventory of pipe if 100 miles are replaced?"
  - Allows for individual assets with unique characteristics to be identified
- Addressing changes in LoF by specifying a complete post-mitigation probability distribution for all assets (e.g., all pipe of all diameters, operating pressures, etc.) requires unduly complex probabilistic analysis to do accurately
  - Simply assuming a change in the probability distribution on the number of failures system-wide is not credible (problem is too large and complex)
  - JIA methodology computes this distribution from more granular inputs

Benefits of a Bottom-up Methodology (cont'd)

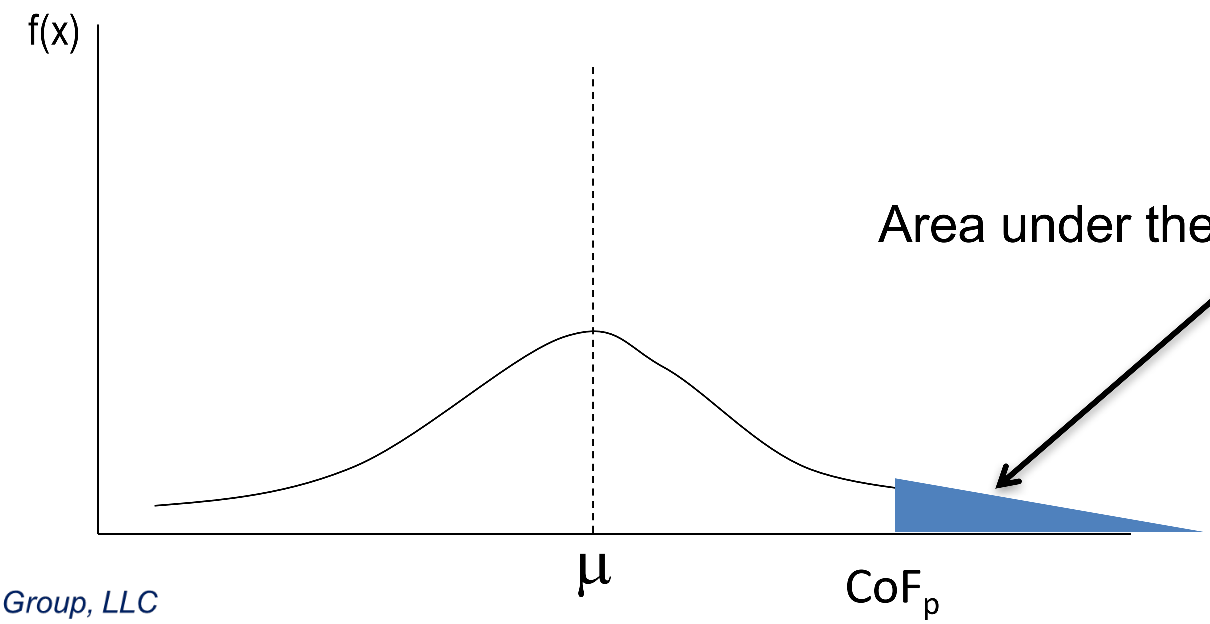
- "Bottom-up" approach allows specific components to be evaluated using sensitivity analysis where data are limited
  - Example: how do changes in LoF values effect RSE for different types of pipe?
  - Example: how do changes in CoF attribute ranges (e.g., environmental damages) affect RSE?
  - Example: how do changes in operating characteristics affect RSE?
  - A study of sensitivities helps the utility to identify what information it would be valuable to collect.

Expected Values and "Tail Risk"

- Not appropriate to use "Tail Risk" as a measure of risk reduction
- Tail Risk is a misnomer
  - Risk is measured by an expected value.
  - Risk is not a probability distribution, hence misleading to consider something called "tail risk"

Expected Values and "Tail Risk" (cont.)

- The CoF values provided by the utilities already include these extreme consequences
  - CoF is a probability distribution, hence it has a "tail."
  - In the figure, CoF can exceed an "extreme" level, CoF_P, with probability p



Expected Values and "Tail Risk" (cont.)

- If CoF is uncertain, then risk is LoF x E{CoF}.
- Expected value of CoF includes effects of extreme CoF values (why "double-count" the "tail risk"?)
- If CoF is uncertain, then CoF_p can be measured, but the value of "p" is arbitrary (90%? 95%, 99%?)
- Cannot "trade off" expected value and CoF_p in a consistent manner
- Cannot combine expected value and tail risk into a single value that can then be used calculate risk <u>reduction</u>
- Cannot resolve contradictions in recommendations
  - Example: Mitigation A reduces CoF_p but increases E(CoF); Mitigation B reduces E(CoF), but leaves CoF_p unchanged. Which mitigation is preferable? Why?

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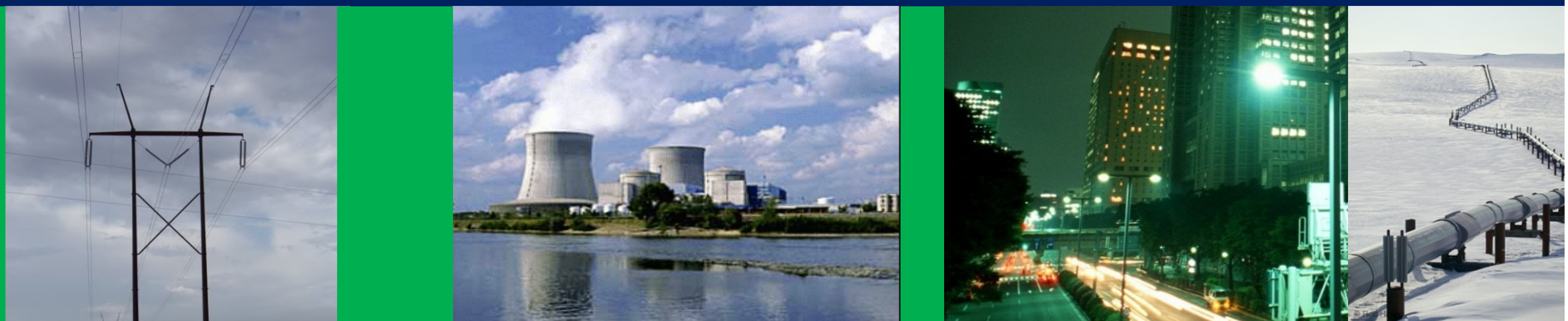

Evaluation Criteria

(Day 2, Afternoon Session)

Evaluation Criteria

- D.16-08-018, p. 114: "We conceptually adopt the Joint Intervenor 'Multi-Attribute' Approach measures listed on pages 90-94 (or utility equivalent features)….
  - LoF based on mathematical probabilities using condition-dependent hazard rates;
  - CoF expressed using a properly designed multi-attribute utility function expressed on a linear scale;
  - Evaluation of risk mitigation measuring the risk reduction per dollar spent; and
  - Replacement of non-optimal ranking methods with actual optimization technique."
- Evaluation should consider to what extent proposed approaches fulfill the criteria listed on pages 90-94 of D.16-08-018

Evaluation Criteria

- D.16-08-018 also identifies other criteria:
  - Fulfillment of stated Commission goals;
  - Ability to cause short-term (and presumably long-term) change;
  - Transparency;
  - Reasonableness and Accuracy of Results;
  - Ease of Preparation and Implementation of Results

Evaluation Criteria: Transparency and Reasonable and Accurate Results

- Transparent data and methodology
  - The sources of all data should be provided
  - Given inputs, a third party should be able to recreate the same results
- Methodologically sound:
  - Must be mathematically correct and logically sound
  - Avoid ad-hoc adjustments to "correct" results that are not logical
- Able to provide consistent and reliable rankings of mitigation alternatives
  - Identify cost-effective mitigation measures consistently, accounting for different measure lifetimes based on levelized present value costs
  - Ability to optimize risk mitigation, given multiple constraints

Evaluation Criteria – Ability to Effectuate Change

- The adopted features and approach should drive utilities to improved risk management and resource allocation, i.e., should change the status quo
  - Changing the status quo is never comfortable
- Adopted features should not be so vague as to allow utilities to simply ratify status quo decisions

Evaluation Criteria: Implementation

- Short term- static analysis prioritizes spending
  - Identify data requirements for dynamic implementation
- Long term- dynamic analysis optimizes resource allocation
- Learning curve for both utilities and intervenors - initial implementation of any new approach will be time intensive, will require cultural shift in how organizations consider risk