PACIFIC GAS AND ELECTRIC COMPANY

CHAPTER 3

RISK ASSESSMENT AND MITIGATION PHASE

RISK MODELING AND RISK SPEND EFFICIENCY

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A. Introduction

This chapter provides a detailed discussion of the Multi-Attribute Value Function (MAVF), Risk Score, and Risk Spend Efficiency (RSE) methodology used to quantitatively assess risks and mitigations throughout this report. It also includes numerical examples to illustrate how these methods are applied.

The Safety Model Assessment Proceeding (S-MAP) Settlement Agreement Decision (the S-MAP Settlement Decision)[1] established minimum requirements that satisfy and expand on Steps 1, 2 and 3 of the Cycla 10-step risk evaluation process.[2] The Commission directs the large Utilities to implement the following steps to analyze risk and mitigation choices in Appendix A of the S-MAP Settlement Decision:[3]

- Building a MAVF – Step 1A
- Identifying Risks for the Enterprise Risk Register[4] – Step 1B
- Risk Assessment and Risk Ranking in Preparation for Risk Assessment Mitigation and Phase (RAMP) – Step 2A
- Selecting Enterprise Risks for RAMP – Step 2B
- Mitigation Analysis for Risks in RAMP – Step 3

Each of the Steps, and the associated sub-steps or "elements" are described in detail in Attachment A, Appendix A to the S-MAP Settlement Decision.

This chapter describes Steps 1A and 3. Steps 1B, 2A, and 2B are described in Chapter 4.

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1 Decision (D.) 18-12-014, Phase Two Decision Adopting Safety Model Assessment Proceeding (S-MAP) Settlement Agreement with Modifications.

2 The Cycla Corporation 10-Step Evaluation Method was adopted in D.16-08-018 as a common yardstick for evaluating the maturity of utility risk assessment and mitigation models. D.18-12-014, pp. 12-14.

3 D.18-12-014, p. 22.

4 PG&E recently renamed its Enterprise Risk Register to its Corporate Risk Register (CRR).

The terms used to describe the different elements of Pacific Gas and Electric Company's (PG&E or the Company) risk model and risk analysis efforts are based on the definitions provided in the S-MAP Settlement Decision.[5] Terms that are not defined in the S-MAP Settlement Decision are defined in this Chapter the first time they are used.

B. Risk Management Approach

PG&E's risk modeling, analysis and mitigation strategy is focused on reducing the potential for catastrophic risk events and the consequences of those events. In terms of risk modeling, this strategy entails paying special attention to tail risk—the low frequency, high consequence events. We achieve this in the 2020 RAMP by using a non-linear scaling function which gives a greater weight in the risk model to low frequency, high consequence events than to high frequency, low consequence events.[6]

PG&E is risk-averse in the sense that term is used in economics. Given a choice between two mitigations that theoretically reduce the same expected amount of loss, one of which is targeted at catastrophic (low frequency, high consequence) risk events and another that is targeted at routine (high frequency, low consequence) risk events, our preference is to select the mitigation that targets the catastrophic events because of the uncertainty of their frequency and consequence. Catastrophic events can have a more severe impact than multiple routine events for numerous reasons, including:

- The maximum scope and consequences of certain catastrophic events, such as a wildfire, are very hard to determine;
- The effects of catastrophic events have the potential to be concentrated in one place and one time, disproportionately affecting communities;
- Catastrophic events can also overwhelm emergency facilities and infrastructure; and
- Catastrophic events can have significant, unforeseen consequences that are not factored into everyday operations and contingency planning, and therefore have a greater potential to disrupt PG&E's operations (compared to multiple low consequence events).

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5 D.18-12-014, Attachment A, pp. A-2 to A-4.

6 PG&E's use of a non-linear scaling function is described in Section C.5, below.

We have learned through experience that the biggest risk events—those that disrupt the lives of our customers, their communities and PG&E itself—are the ones we need to avoid by clearly understanding what drives these events and then taking the right steps to prevent them in the future.

C. Multi-Attribute Value Function

Step 1A in D.18-12-014 requires utilities to build a MAVF to evaluate and rank alternative risk mitigation programs.[7] PG&E's MAVF reflects our focus on low-frequency/high-consequence risk events without neglecting operational risks (high-probability/low-consequence events).

Appendix A lists the six principles according to which the MAVF should be constructed.[8] The six principles are shown in rows 2 through 7 in Table 3-1 below.

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7 D.18-12-014, p. 22.

8 D.18-12-014, Attachment A, pp. A-5 to A-6.

TABLE 3-1
STEP 1A, PRINCIPLE 1 – BUILDING A MULTI-ATTRIBUTE VALUE FUNCTION

Row No.	Element Name	Element Description and Requirements
1	MAVF	A utility's MAVF should be constructed by following these six principles (see Rows 2-7, below). The MAVF is required to be built once, but the utility may adjust its MAVF over time. Any changes to the MAVF must adhere to the principles of construction set forth in Rows 2 through 7 below.
2	MAVF Principle 1 – Attribute Hierarchy	Attributes are combined in a hierarchy, such that the top-level Attributes are typically labels or categories and the lower-level Attributes are observable and measurable.
3	MAVF Principle 2 –Measured Observations	Each lower-level Attribute has its own range (minimum and maximum) expressed in natural units that are observable during ordinary operations and as a consequence of the occurrence of a risk event.
4	MAVF Principle 3 – Comparison	Use a measurable proxy for an Attribute that is logically necessary but not directly measurable. This principle only applies when a necessary Attribute is not directly measurable. For example, a measure of the number of complaints about service received can be used as a proxy for customer satisfaction.
5	MAVF Principle 4 – Risk Assessment	When Attribute levels that result from the occurrence of a risk event are uncertain, assess the uncertainty in the Attribute levels by using expected value or percentiles, or by specifying well-defined probability distributions, from which expected values and tail values can be determined. Monte Carlo simulations or other similar simulations (including calibrated subject expertise modeling), among other tools, may be used to satisfy this principle.
6	MAVF Principle 5 – Scaled Units	Construct a scale that converts the range of natural units (from Row 3) to scaled units to specify the relative value of changes within the range, including capturing aversion to extreme outcomes or indifference over a range of outcomes. The scaling function can be linear or non-linear. For example, the scale is linear if the value of avoiding a given change in Attribute level does not depend on the Attribute level. Alternatively, the scale is non-linear if the value of avoiding a given change in Attribute level differs by the Attribute level.
7	MAVF Principle 6 – Relative Importance	Each Attribute in the MAVF should be assigned a weight reflecting its relative importance to other Attributes identified in the MAVF. Weights are assigned based on the relative value of moving each Attribute from its least desirable to its most desirable level, considering the entire range of the Attribute. One means of incorporating a weighting process was presented in the February 17, 2017 Report of Joint Intervenor Test Drive Step 1 Results, "Specifying the Multi-Attribute Value Function," by Drs. Feinstein and Lesser. Weights are assigned based on actual Attribute measurement ranges, not a fixed weight arbitrarily assigned to an Attribute. *However, given the California Public Utilities Commission's (CPUC or Commission) focus on safety, a minimum of 40 percent safety weight is established unless the Utilities can justify a lower weight based on their respective analyses. This requirement supersedes the other specifications stated above.* For example, the Attribute weights will reflect the relative importance of moving the safety outcomes from the least to the most desirable levels as compared with moving financial outcomes from the least to the most desirable levels in a risky situation.

1. Implementing MAVF Principle 1 – Attribute Hierarchy

Principle 1 requires that Utilities identify Attributes that are combined in a hierarchy such that the top level Attributes are categories and the lower level Attributes, or sub-Attributes, are observable and measurable.[9]

PG&E identified four Attributes: (1) Safety, (2) Electric Reliability, (3) Gas Reliability, and (4) Financial, each with one lower-level Attribute.

1) "Safety" has one lower-level observable and measurable attribute: Equivalent Fatalities (EF).
2) "Electric Reliability" has one lower-level observable and measurable attribute: Customer Minutes Interrupted (CMI).
3) "Gas Reliability" has one lower-level observable and measurable attribute: Number of Customers Affected.
4) "Financial" has one lower-level attribute: U.S. Dollars. Pursuant to D.18-12-014 and D.16-08-018, shareholders' financial interests are excluded.[10]

2. Implementing MAVF Principle 2 – Measured Observations

MAVF Principle 2 requires that each lower-level Attribute have its own minimum and maximum range expressed in natural units that are observable during ordinary operations and as a Consequence of a Risk Event (CoRE).[11] Table 3-2 below summarizes PG&E's Attributes and associated ranges.

TABLE 3-2
STEP 1A, PRINCIPLE 2 – MEASURED OBSERVATIONS

Line No.	Attribute	Natural Unit of Attribute	Range
1	Safety	EFs	0 – 100
2	Electric Reliability	CMI	0 – 4 billion
3	Gas Reliability	Number of Customers Affected	0 – 750 thousand
4	Financial	Dollars	0 – 5 billion

[9] D.18-12-014, Attachment A, p. A-5, No. 2.

[10] D.18-12-014, p. 29, and D.16-08-018, p. 193, Conclusion of Law (COL) 37.

[11] D.18-12-014, Attachment A, p. A-5, No. 3.

The S-MAP Settlement Decision defines the low and high end of the Range of the Natural Unit to be a smallest and largest observable value from a risk event.[12] PG&E uses the term Upper Bound to denote the highest value in a Range. However, given the uncertainty in what the largest observable outcome of a risk event might be, PG&E defines the Ranges based on historical events and plausible high-consequence scenarios. PG&E defines each of the natural units of the Attribute as follows:

- An Equivalent Fatality is defined as the sum of Fatalities and Serious Injury Equivalents per event occurrence. Serious Injury is defined as an injury that requires in-patient hospitalization of an individual pursuant to existing Federal and State reporting guidelines.[13],[14] Fatalities and Serious Injuries are converted to EFs using the factors shown in Table 3-3. The conversion rate from Serious Injury to EF is based on the disutility factors for Serious Injuries relative to Fatality available from Federal sources.[15] The Upper Bound of the Range for the Safety Attribute is based on EFs resulting from the Camp Fire rounded up to 100.

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12 D.18-12-014, Attachment A, p. A-3.

13 Pipeline and Hazardous Materials Safety Administration (PHMSA) § 191.3, Definitions: Incident. See also: <https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-facility-incident-report-criteria-history>, accessed June 25, 2020.

14 D.98-07-097, Appendix B, Accident Report Requirements, par. 3. See also, <https://www.cpuc.ca.gov/General.aspx?id=2090>, accessed June 22. 2020.

15 See Federal Aviation Administration (FAA) Office of Aviation Policy and Plans, Treatment of the Values of Life and Injury in Economic Analysis, p. 2-3, Table 2-3, Updated September 2016, aaccessed June 19, 2020, at: <https://www.faa.gov/regulations_policies/policy_guidance/benefit_cost/media/econ-value-section-2-tx-values.pdf>.

TABLE 3-3
EQUIVALENT FATALITY CONVERSION FACTORS
SIMULATED FATALITY OR SERIOUS INJYRY QUANTITIES

Line No.	Type	Equivalent Factor
1	Fatality	1.00
2	Serious Injury	0.25

- The Electric Reliability Upper Bound is based on the October 26-29, 2019 Public Safety Power Shutoff event consequence of approximately 3.6 billion CMI rounded up to 4 billion.
- The Gas Reliability Upper Bound is based on a scenario of an outage at a critical gas facility.
- The Upper Bound of the Financial Range represents a financial loss commensurate with a 2000-2001 Energy Crisis-type event. Costs related to recent wildfires were not used to set the Upper Bound because, pursuant to D.18-12-014, utility shareholders' financial interests are excluded from consideration.

3. Implementing MAVF Principle 3 – Comparison

MAVF Principle 3 directs Utilities to use a measurable proxy for any Attribute that is logically necessary, but not directly measurable.[16] Since all PG&E's Attributes are directly measurable, proxies are not used.

4. Implementing MAVF Principle 4 – Risk Assessment

MAVF Principle 4 states that when Attribute levels resulting from the occurrence of a risk event are uncertain, the utility should assess the uncertainty in the Attribute levels using expected values or percentiles, or by specifying well-defined probability distributions from which expected values and tail values can be determined. Monte Carlo simulations may be used to satisfy this principle.[17]

PG&E employs a probabilistic approach to modeling Attribute levels. The Attributes are specified by well-defined conditional probability distributions with parameters derived from data and/or calibrated subject

[16] D.18-12-014, Attachment A, p. A-5, No. 4.

[17] D.18-12-014, Attachment A, p. A-5, No. 5.

matter expert (SME) input. Monte Carlo methods are used to simulate Attribute levels from these distributions. Details about PG&E's Risk Assessment methodology and a numerical example are presented in Section D.

5. Implementing MAVF Principle 5 – Scaled Units

MAVF Principle 5 requires Utilities to construct a scale that converts the range of natural units to scaled units to specify the relative value of changes within the range.[18]

The S-MAP Settlement Decision defines the Scaled Unit of an Attribute as a value that varies from 0 and 100. The Scaled unit is set to 0 for the most desirable level, and 100 for least desirable level.[19] For any level of the attribute between the most desirable and least desirable levels, the Scaled Unit is between 0 and 100. Consistent with the S-MAP Settlement Decision, PG&E's Scaled Units reflect a 0-to-100-point scale, where zero reflects no adverse consequences (i.e., no EFs, no reliability impact, or no financial loss) and 100 corresponds to the Upper Bound of the Attribute Range.

MAVF Principle 5 provides that the scale described above can be constructed so as to "captur[e] aversion to extreme outcomes or indifference over a range of outcomes"[20] and that the "scaling function can be linear or non-linear."[21] As described in Section B, above, PG&E's risk management objective is to prioritize the mitigation of risks characterized as low frequency/high consequence (LFHC) events, even though their expected loss might be the same as multiple high frequency events with low consequences. To reflect this objective, PG&E uses a non-linear scaling function that captures aversion to extreme outcomes, rather than using a linear Scaling Function that would yield indifference over a range of outcomes.

In the 2017 RAMP Report, PG&E used two measures of risk, the Mean (i.e., the average of simulated losses), and the 90-100 percent Tail Average

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18 D.18-12-014, Attachment A, pp. A-5 to A-6, No. 6.

19 D.18-12-014, Attachment A, p. A-3.

20 D.18-12-014, Attachment A, p. A-5, No. 6.

21 D.18-12-014, Attachment A, p. A-6, No. 6.

(i.e., the average of the worst 10 percent of simulated losses).[22] We considered the 90-100 Tail Average to be an important metric because of our desire to focus on the identification, evaluation and reduction of catastrophic risks, given our past experience with risks.[23] Events since the 2017 RAMP Report, especially the Camp Fire, have highlighted and validated the need for a continued focus on high consequence, low probability risk.

The S-MAP Settlement Decision that sets forth the requirements for the 2020 RAMP does not give PG&E the opportunity to use the Tail Average as a metric. The S-MAP Settlement Decision adopted a single measure of risk—the Risk Score— which is the product of the Likelihood of a Risk Event (LoRE) and the Consequence of a Risk Event (CoRE). The S-MAP Settlement Decision further defines CoRE to be the weighted sum of the scaled values of the level of the individual Attributes using the MAVF.[24]

One effect of using the Expected Value of Attributes as the sole measure for CoRE is that the tail risk of risk events may be obscured, depending on what scaling function is used. A linear scaling function essentially adopts the average of risk event outcomes as the measure of the risk. It is indifferent to the distribution of those outcomes. Consider the scenarios shown in Figure 3-1 and Figure 3-2 below, which represent the potential safety consequence of two hypothetical risk events:

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22 PG&E's 2017 RAMP Report, Investigation (I.) 17-11-003 (Nov. 30, 2017) (PG&E's 2017 RAMP Report), pp. B-15 to B-16.

23 PG&E's 2017 RAMP Report, p. B-16.

24 D.18-12-014, Attachment A, p. A-11, No. 13.

FIGURE 3-1
HIGH FREQUENCY, LOW CONSEQUENCE EVENT WITH MEAN LOSS OF $150

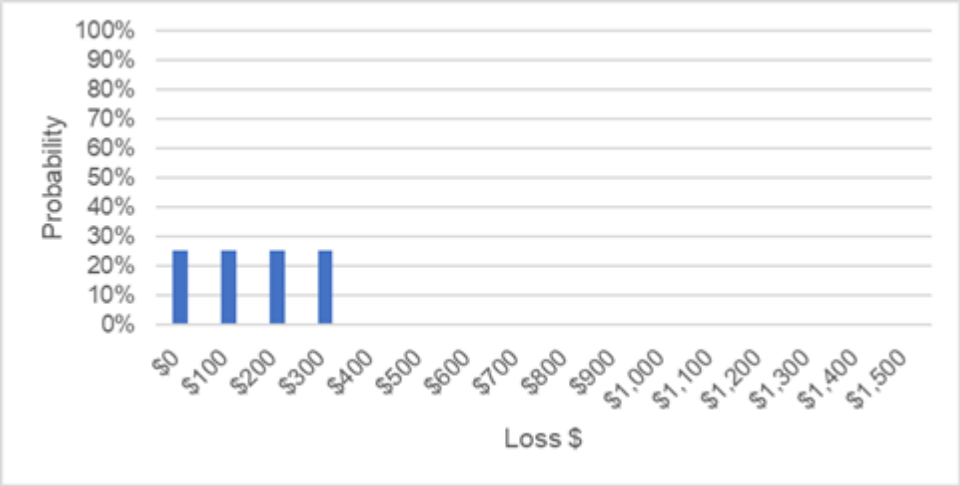

FIGURE 3-2
LOW FREQUENCY, HIGH CONSEQUENCE EVENT WITH MEAN LOSS OF $150

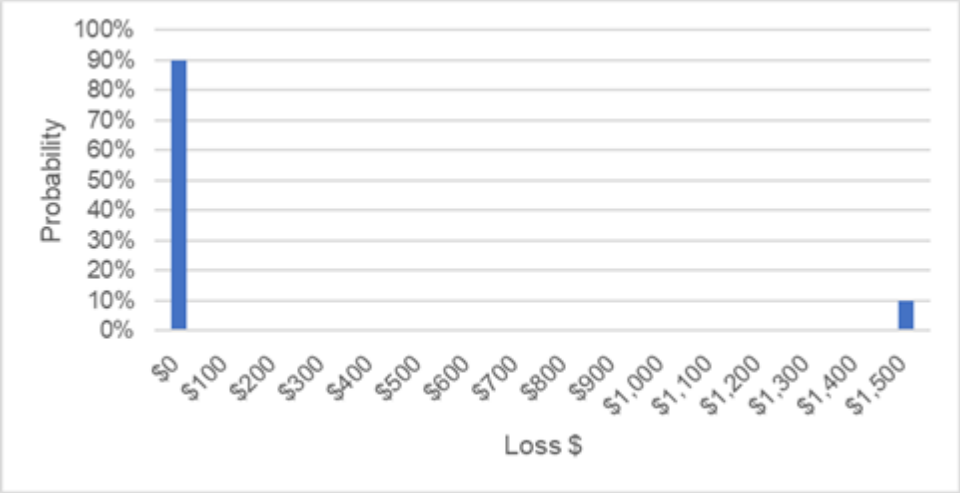

Figure 3-1 represents a high frequency, low consequence event. 75 percent of the risk events result in a loss, but the losses are small ($100-300 in this example). Figure 3-2 represents a low frequency, high consequence (i.e. catastrophic) event. Only 10 percent of the risk events result in a loss, but that loss is large ($1,500). In both cases, the mean loss for all the risk events considered together is the same—$150.[25] Because their mean loss is the same, a linear scaling function would treat these two

[25] (0.25 x $100) + (0.25 x $200) + (0.25 x $300) = $150 = 0.10 x $1500.

risks similarly, despite the large difference in the distribution of risk outcomes.[26] By contrast, as described below, a non-linear scaling function assigns a greater weight to low frequency high, consequence risk events, so that mitigations for the risk in Figure 3-2 would be prioritized over mitigations for the risk shown in Figure 3-1. PG&E uses non-linear scaling function because it allows us to better understand tail risk and prioritize mitigations for low frequency, high consequence events, consistent with our risk management objectives.

In academic settings, MAVFs are used in conjunction with a utility function[27] when extending standard, single-attribute utility theory to a multi-attribute setting. The MAVF first establishes an ordering preference for all the different combinations of attribute levels. The utility function, either on its own or together with the MAVF, is then used to express risk preference (i.e., risk-aversion, risk-seeking or risk-neutral). However, that possibility does not exist in the framework of the S-MAP Settlement Decision, which requires expected values to be used for the CoRE,[28] basically giving CoRE the role of the utility function. The S-MAP Settlement Decision further requires that, "The CoRE is the weighted sum of the scaled values of the levels of the individual Attributes using the utility's full MAVF."[29] Mathematically, this implies $U(V(a)) = V(a)$, where U is the utility function and V is the expected value of the multi-attribute value function. The utility function is risk-neutral and, in the context of the S-MAP Settlement Decision, cannot be used to express risk aversion. Therefore, the only way to express aversion to catastrophic risk is through the Scaling Function, consistent with MAVF Principle 5.

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26 In Economics theory, Figure 3-2 is a Mean-Preserving Spread of Figure 3-1. Risk-averse individuals will prefer Figure 3-1 to Figure 3-2.

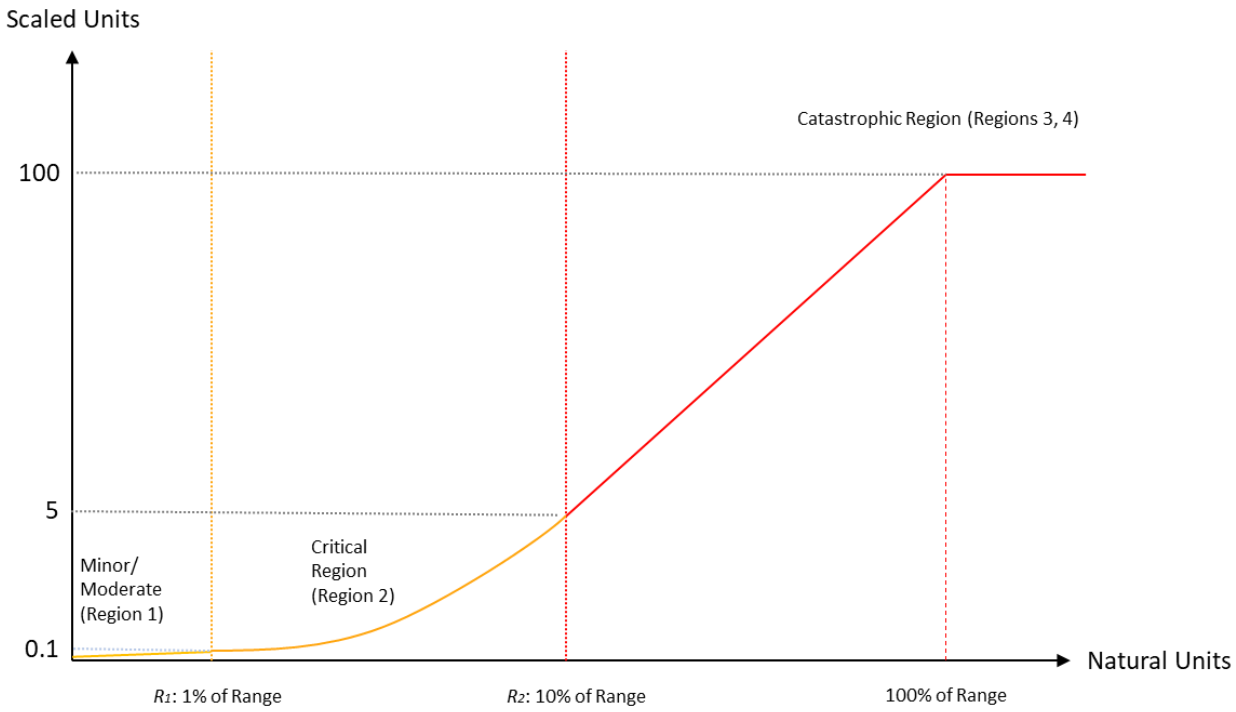
27 In general economics, a utility function measures preferences concerning a set of alternatives. Here, utility refers to the general sense of the word (i.e., "utility: fitness for some purpose or worth to some end"). Merriam-Webster.com Dictionary, s.v. "utility," accessed June 19, 2020, at <https://www.merriam-webster.com/dictionary/utility>.

28 D.18-12-014, Attachment A, pp. A-12 to A-13, No 24.

29 D.18-12-014, Attachment A, p. A-11, No 13.

The non-linear Scaling Function used by PG&E consists of three regions that define its overall shape, illustrated in Figure 3-3. Each of the regions is described below.

FIGURE 3-3
NON-LINEAR SCALING FUNCTION FOR PG&E'S MAVF



a) Minor/Moderate Region: Linear for natural unit consequence from 0 percent to 1 percent of the Range. Events whose consequence result in this region are assigned Scaled Units between 0 and 0.1.

b) Critical Region: Quadratic for natural unit consequence from 1 percent to 10 percent of the Range. Events whose consequence result in this region are assigned Scaled Units between 0.1 and 5.

c) Catastrophic Region: Linear for natural consequence from 10 percent to 100 percent of the Range (catastrophic events). Events whose consequence results in this region and beyond 100 percent of the Range are assigned Scaled Units between 5 and 100.

Mathematically, the Scaling Function, *S(r)*, used for all Attributes is defined in Equation 1.

FIGURE 3-4
EQUATION 1: SCALING FUNCTION FOR ALL ATTRIBUTES

$$S(r) = \begin{cases} 10r, & \text{Region 1: } r \le R_1 \\ 10r + \frac{1}{2}.\frac{100(0.99-0.10)}{(R_2-R_1)}(r-R_1)^2 & \text{Region 2: } R_1 < r \le R_2 \\ \frac{100-S_2}{(1.0-R_2)}(r-R_2)+S_2, & \text{Region 3: } R_2 < r \le 100\% \\ 100, & \text{Region 4: } r > 100\% \end{cases}$$

where

a: *Attribute Level (e.g. $ loss)*
R: *Upper Range of Attribute (e.g. $5billion for Financial)*
$r = \frac{a}{R}$: *Normalized Attribute Level*

R_1 *=1% (Upper bound of Minor/Moderate Region)*
R_2 *=10% (Upper bound of Critical Region)*

S_1 *=0.1 (Maximum value in Minor/Moderate Region)*
S_2 *=5 (Maximum value in Critical Region)*

For consequences in the minor/moderate region (Region 1), representing high-frequency/low-consequence events, a linear function with a relatively small coefficient is adequate because the resulting low consequence value is multiplied by a relatively high frequency of occurrence when risk scores are calculated.

As the consequence from a risk event enters the critical level (defined as 1 percent of the Upper Bound), PG&E's Scaling Function reflects growing risk aversion through a quadratic function. In the Critical region (Region 2), PG&E assigns an incremental value of between approximately 1 to 10 times the value of an incremental loss in a minor/moderate situation. This increase in Scaled Units can be seen in the increasing slope of a scaling function:

- Going from an Attribute level of 2 percent to 2.1 percent is approximately twice the increase in Scaled Units going from 0.0 percent to 0.1 percent;
- The increase in Scaled Units going from an Attribute level of 5 percent to 5.1 percent is approximately five times the increase when going from 0.0 percent to 0.1 percent; and,

- The increase in Scaled Units going from an Attribute level of 9.9 percent to 10 percent is approximately 10 times the increase when going from 0.0 percent to 0.1 percent.

These increases were achieved by calibrating the quadratic coefficient.

Throughout the Catastrophic region (Region 3), incremental losses are assigned approximately 10 times the value of an incremental loss in a minor/moderate situation. The increase in Scaled Units (i.e. slope) going from an Attribute level of either 10 percent to 10.1 percent or 99.9 percent to 100 percent is about 10 times more than the increase going from 0.0 percent to 0.1 percent. This consistent increase is illustrated by the constant slope of the scaling function in the Catastrophic region in Figure 3.4. The linear coefficient for Region 3 was set to be approximately 105.6 to achieve this consistent increase.

PG&E places a maximum value of 100 on the Scaled Units and does not constrain the underlying Attribute level to the Range. For consequences above the Attribute Range, the Scaled Unit is capped at 100. Capping the scaled units has the effect of treating all extreme tail end results the same in the risk model even though it is possible that the consequences of an extreme event could exceed the maximum value of the Attribute Range.

6. Implementing MAVF Principle 6 – Relative Importance

MAVF Principle 6 states that each Attribute should be assigned a weight reflecting its importance relative to other Attributes defined in the MAVF.[30]

PG&E uses the Attribute Weights shown in Table 3-4.

TABLE 3-4
ATTRIBUTE WEIGHTS

Line No.	Attribute	Weight
1	Safety	50%
2	Electric Reliability	20%
3	Gas Reliability	5%
4	Financial	25%

[30] D.18-12-014, Attachment A, p. A-6, No. 7.

PG&E assigned the Attribute Weights to reflect the relative importance of moving each Attribute from its least desirable level (i.e., Upper Bound) to its most desirable level (i.e., zero). For example, the Attribute Weights reflect PG&E's view that it is twice as valuable to move the Safety Attribute from 100 to 0 EFs as it is to move the Financial Attribute from $5 billion to $0. Assigning 50 percent weight to the Safety Attribute is in line with PG&E's emphasis on safety and is also consistent with the S-MAP Settlement Decision's requirement for a minimum 40 percent weighting for Safety.[31]

D. Risk Assessment

This section describes how PG&E implemented Step 3, Mitigation Analysis for Risks in RAMP. The objective of this section is to explain the methodology used to develop the 12 models which probabilistically assess the likelihood and consequence of various risks events reported in PG&E's 2020 RAMP Report, Chapters 7 through 18. Each of these models produces a 2023 Baseline Risk Score, which is calculated using the methodology discussed in Section D.1.d, below.

1. Bow Tie Methodology

All RAMP risk chapters include a Bow Tie illustration, which gives a visual summary of the drivers and CoRE. In the center of the Bow Tie is the risk event, which is a well-defined, single, observable and measurable event. In the example Bow Tie below, Figure 3-5, the Risk Event is a Loss of Containment (LOC) on a Gas Transmission Pipeline.

In the following sections PG&E describes each of the Bow Tie elements: drivers/frequency; outcomes/consequences; the risk score; and the cross-cutting factors.[32]

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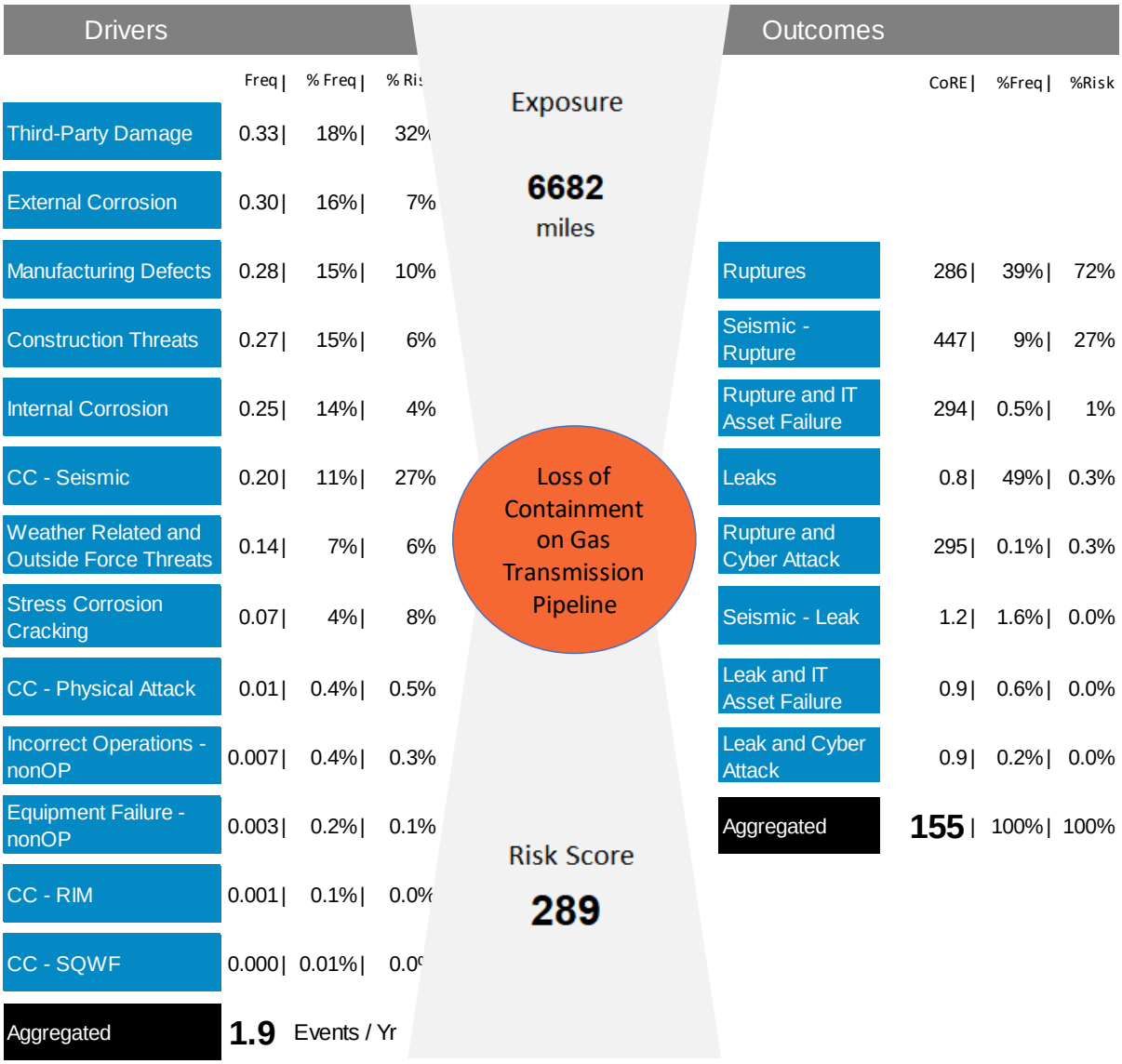
[31] D.18-12-014, p. 66, COL 5.

[32] Cross-cutting factors are not risk events themselves but rather they impact either the likelihood or consequence of other risk events. The cross-cutting factors are shown on the left side of the Bow Tie preceded by the letters "CC." On the right side of the Bow Tie they are shown in combination with other consequence events (i.e., Leak and Cyber Attack where leak is a loss of containment outcome and cyber attack is the cross-cutting factor).

The risk score shown at the bottom of the Bow Tie, in the center, is calculated as the likelihood of the risk event multiplied by the consequence of the risk event (LoRE x CoRE). Calculating the risk score is described in more detail below.

Please note the CoRE shown in the Bow Tie includes a scaler of 1,000.

FIGURE 3-5
RISK EVENT BOW TIE: LOSS OF CONTAINMENT ON A GAS TRANSMISSION PIPELINE



a. Frequency of a Risk Event

On the left-hand size of the Bow Tie are the Risk Event drivers and their associated frequencies. The set of drivers includes the causes or

threats identified for the Risk Event. Drivers are measurable events. The annual frequency of a risk driver leading to a Risk Event is informed by PG&E event data that is supplemented with industry data and/or SME input when necessary. Certain drivers are further divided into multiple sub-drivers (components of a risk driver),[33] where the further division is useful and where data are available. Risk and mitigation analysis can also be done at a sub-driver level.

Drivers are expressed as the frequency of occurrence of a Risk Event per exposure *per year*, the time unit for the analysis. For example, Figure 3-5 shows a frequency of 0.33 for the Third-Party Damage driver (top left side of the figure) which means that in 2023 PG&E expects to have 0.33 loss of containment events on a gas transmission pipeline due to third-party damage events if no mitigations are implemented starting in 2023. The frequency of a Risk Event associated with each driver is summed to establish the risk-level frequency. Without implementing any mitigations starting in 2023, PG&E expects to have 1.9 loss of containment events—the aggregated number of events shown in the lower left corner of the Bow Tie.

b. Potential Consequence of a Risk Event

On the right-hand side of the Bow Tie, PG&E introduces Outcomes to differentiate manifestations of a risk event that have significantly different consequences (changes in Attribute levels representing the impact of the outcome). Each Outcome is characterized by different probability distributions over the applicable Attributes, determined from PG&E data, industry data, and/or SME input. The consequences of the Risk Event are shown in more detail in the Consequence Table in each RAMP risk chapter. Figure 3-6 below is the Consequence Table for the LOC on a Gas Transmission Pipeline risk.

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33 For example, the risk driver "Vegetation" in the Failure of Electric Distribution Overhead Assets risk event includes three sub-drivers: tree contract; right-of-way encroachment; and, tree trimming.

FIGURE 3-6
CONSEQUENCE TABLE: LOSS OF CONTAINMENT ON A GAS TRANSMISSION PIPELINE

	CoRE	%Freq	%Risk	Freq	Natural Units Per Event			CoRE			Natural Units per Year			Attribute Risk Score		
					Safety EF/event	Gas Reliability #cust/event	Financial $M/event	Safety	Gas Reliability	Financial	Safety EF/yr	Gas Reliability #cust/yr	Financial $M/yr	Safety	Gas Reliability	Financial
Ruptures	286	39.0%	72%	0.7	1.0	41,573	5.3	115.0	164.8	5.8	0.7	30,234	3.9	83.6	119.9	4.2
Seismic - Rupture	447	9.2%	27%	0.2	1.7	48,067	8.5	247.2	189.0	11.0	0.3	8,261	1.5	42.5	32.5	1.9
Rupture and IT Asset Failure	294	0.5%	1%	0.0	1.0	42,149	5.4	119.7	169.0	5.5	0.0	403	0.1	1.1	1.6	0.1
Leaks	0.8	48.7%	0.3%	0.9	0.0	22	1.2	0.2	0.0	0.6	0.0	20	1.1	0.2	0.0	0.5
Rupture and Cyber Attack	295	0.1%	0.3%	0.0	1.0	42,059	5.6	120.4	168.4	6.0	0.0	106	0.0	0.3	0.4	0.0
Seismic - Leak	1.2	1.6%	0.0%	0.0	0.0	33	1.7	0.3	0.0	0.9	0.0	1	0.1	0.0	0.0	0.0
Leak and IT Asset Failure	0.9	0.6%	0.0%	0.0	0.0	23	1.3	0.2	0.0	0.6	0.0	0	0.0	0.0	0.0	0.0
Leak and Cyber Attack	0.9	0.2%	0.0%	0.0	0.0	22	1.3	0.2	0.0	0.6	0.0	0	0.0	0.0	0.0	0.0
Aggregated	**155**	100%	100%	1.9	0.6	20,939	3.5	69	83	4	1.0	39,025	6.6	128	154	7

For reference, the attribute ranges are shown again below – Table 3-2 (above):

Line No.	Attribute	Natural Unit of Attribute	Range
1	Safety	EFs	0 – 100
2	Electric Reliability	Customer Minutes Interrupted	0 – 4 billion
3	Gas Reliability	Number of Customers Affected	0 – 750 thousand
4	Financial	Dollars	0 – 5 billion

In the LOC on a Gas Transmission Pipeline risk above, the consequences of a LOC event include the potential for serious injury or fatality (Safety), loss of gas service (Gas Reliability), and property damage (Financial). The manifestation of these consequences depends on the Outcome that causes the loss of containment. A leak is sufficiently different from a rupture that modelling them both with a single consequence attribute distribution does not fairly characterize either. Having different sets of Attribute distributions for each Outcome more precisely models the potential consequences of the Risk Event.

The probability distributions characterizing Safety, Financial and Gas Reliability Consequence for the leak outcome are lower in mean and variance across the attributes than the set of distributions for a rupture. Furthermore, some drivers are more or less likely to lead to lower or higher severity outcomes. For example, the Third-Party Damage driver leads only to the rupture outcome, not a leak. In contrast, External Corrosion, an important driver of LOC events, is more likely to lead to a leak than to a rupture. Through this analysis, PG&E can better identify and mitigate drivers strongly tied to the more severe outcomes when elements on the left- and the right-hand side of the Bow Ties are presented as specifically as possible, given the available information.

The Bow Tie illustrated in each RAMP risk chapter lists drivers and outcomes of the Risk Event, as well as the associated summary quantities such as frequency, consequence and contribution to risk score. Within PG&E's enterprise risk model, those elements can vary

by one or more of: time, tranche, sub-driver, outcome, and attribute as summarized in Table 3-5.

TABLE 3-5
SUMMARY OF BOW TIE ELEMENT UNITS AND DIMENSIONALITY

Line No.	Bow Tie Element	Quantification Unit	Can Vary By
1	Exposure	Depends on risk event (e.g., miles of pipe, number of high hazard dams, number of employees)	• Time • Tranche
2	Driver	Expected number of risk events per year (frequency)	• Time • Tranche • Sub-driver • Outcome
3	Outcomes	CoRE	• Time • Tranche • Attribute

c. Tranches

For each Risk Event, underlying the Bow Tie structure is a set of tranches over which driver frequencies and Outcome attribute distributions vary both in applicability and magnitude. Each tranche includes a group of assets, a geographic region or other grouping that is intended to have a similar risk profile. For example, the Employee Safety Incident Risk includes two tranches—Office Employees and Field Employees—distinct groups of employees with similar risk profiles within each tranche. The Bow Tie is essentially defined at a tranche level which provides a more granular view of risk and how mitigations will reduce risk.

d. Calculating the Risk Score

Each RAMP risk has an associated Risk Score that is the product of the LoRE and the CoRE.[34]

Risk Score per Unit of Exposure = LoRE x CoRE

[34] D.18-12-014, Attachment A, p. A-11, No. 13.

CoRE is the weighted sum of Scaled Units representing the consequence from an occurrence of a Risk Event on each Attribute using the MAVF. To calculate CoRE using Attribute Weights and Attribute Scaled Units, PG&E applies a Scaler of 1000. Specifically,

CoRE = Safety CoRE + Electric Reliability CoRE+ Gas Reliability CoRE + Financial CoRE

Where:

- *Safety CoRE = Scaler (1,000) x Safety Weight (50%) x Safety Scaled Unit*
- *Electric Reliability CoRE = Scaler (1,000) x Electric Reliability Weight (25%) x Electric Reliability Scaled Unit*
- *Gas Reliability CoRE = Scaler (1,000) x Gas Reliability Weight (5%) x Gas Reliability Scaled Unit*
- *Financial CoRE = Scaler (1,000) x Financial Weight (20%) x Financial Scaled Unit*

PG&E treats LoRE as specified per unit of exposure and expresses Risk Scores equivalently as Frequency x CoRE at a Tranche or System level:

$$\textit{Tranche Risk Score} = \textit{Tranche Exposure} \times \textit{LoRE} \times \textit{CoRE} = \textit{Tranche Frequency} \times \textit{CoRE}$$

Risk Score = Sum of Tranche Risk Scores over all Tranches for the Risk Event

Frequency (the number of occurrences per year) is directly observable and easily understood. For events that are expected to happen less than once per year per unit of exposure, the likelihood of the risk event happening in a year for a Tranche and the frequency of the risk event happening are equivalent (e.g., a 100-year flood has an annual probability, or LoRE, of 0.01, and, the expected number of floods per year, Frequency, is 0.01). For risk events that are expected to happen more often than once per year per unit of exposure, the likelihood of the risk event is 1 though the frequency of the risk event is greater than 1. Frequency captures the difference between a risk event

that happens twice per year and 1,000 times per year, whereas likelihood, as a metric, is unable to do so given a one-year time period for analysis.[35]

e. Test Year Baseline Risk Score

Throughout this RAMP report, all Bow Ties show the Test Year (TY) Baseline Risk Scores for 2023—the TY for PG&E's next General Rate Case (GRC). Test-Year Baseline Risk Scores for 2023 are calculated based on Frequency and Consequence of the Risk Event and may be adjusted for estimated increases due to factors such as climate change and cyber attacks and adjusted for estimated reductions in Frequency and Consequence due to the effectiveness of mitigations that are implemented prior to the start of 2023 GRC period.

2. Modeling the Cross-Cutting Factors

Cross-cutting factors are not risk events themselves but rather they impact either the likelihood or consequence of other items (risk events) on PG&E's CRR.

PG&E presented three cross-cutting factors in its 2017 RAMP. The cross-cutting risk model was dependent on the outputs from the other stand-alone risk models. The cross-cutting models were not specific risk events, but an aggregation of the associated stand-alone risk; each of the stand-alone risks estimated what portion of the risk could be attributed to a cross-cutting factor issue.

For the 2020 RAMP PG&E uses a new approach for presenting and modeling cross-cutting factors. This new approach is responsive to feedback from the Safety Enforcement Division (SED) that PG&E's approach to modelling cross-cutting factors in the 2017 RAMP lacked specificity and transparency into the impact of the drivers and how they are

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35 A potential approach to this issue would be to vary the period for analysis (i.e., a month, a day) in order to compute a LoRE < 1. However, PG&E believes that varying the analysis period from a year would add complexity without substantial benefit, especially since PG&E's enterprise risks have frequencies ranging in order of magnitude from 10^{-3} to 10^{4}.

causally linked to the risk event.[36] In the 2020 RAMP, PG&E is now integrating each applicable cross-cutting factor into the appropriate RAMP risk models as a driver, driver component or consequence of that specific risk. This new approach increases transparency and demonstrates how the cross-cutting factors contribute to the frequency and/or consequence of the RAMP risk events.

As described in Chapter 20, Cross-Cutting Factors, there are four ways the cross-cutting factors are included in the event-based risk models.

a) Driver: Appears on the left-hand side of the Bow Tie as a driver and is modeled identically to other drivers. Frequency of a Risk Event associated with cross-cutting drivers is identified in the same manner as for the other drivers based on historical frequency of those events, or SME judgement if historical data is not available or sufficient.

b) Consequence Multiplier: When a cross-cutting factor affects a consequence of an event for an Outcome regardless of drivers, it is modeled as a Consequence Multiplier to the Natural Unit of the simulated risk event outcome, affecting the CoRE.

c) Outcome: Where the impact of a cross-cutting driver differs from the impact of the non-cross cutting drivers on the consequences of a Risk Event (e.g., the severe Seismic outcome is driven solely by the Seismic driver).

d) Escalating Frequency: Is applied as a Frequency Multiplier over time to one or more applicable risk drivers (e.g., climate change).

3. Modeling the Mitigations and Control Programs

A mitigation is commonly defined as a measure or activity proposed or in process that is designed to reduce the impact/consequences and/or the likelihood/probability of a risk event. The adequacy and effectiveness of a mitigation is assessed based on how much of the exposure is affected (i.e., scope of mitigation), the impact on specific driver/sub-driver

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36 SED noted that PG&E's 2017 approach to modelling cross-cutting risks lacked the specificity and transparency into the impact of the drivers and how they are causally linked to the risk event. SED noted that it might be best to include the cross-cutting drivers in the appropriate stand-alone risk chapter to prevent duplication and better show how these components of risk contribute to the frequency of the risk event. PG&E, Risk and Safety Aspects of RAMP Report, I.17-11-003 (Mar. 30, 2018), p. 24.

frequencies (and how those frequencies may change over time), the impact on the consequence of specific attributes, and the associated cost.

A control is a currently established measure that modifies risk, such as standard operation/routine work that is undertaken as part of normal business operations and is not a new program, or an enhancement to an existing one.[37] Controls have no end date.

The benefits of applying mitigations and controls are represented by percentage reductions in driver/sub-driver frequencies by tranche and outcome, and/or consequence magnitude (e.g., the number of customer minutes interrupted per risk event outcome as simulated) by tranche and outcome. Mitigations are further defined by the duration of risk reduction benefits once mitigation is complete, and effectiveness degradation with time.

PG&E developed mitigation effectiveness workpapers for each mitigation (excluding foundational mitigations that support risk reduction activities but do not reduce risk themselves) and two controls (Gas Operations Leak Management and Electric Operations Enhanced Inspections). The mitigation effectiveness workpapers outline the effectiveness of each mitigation, justification for that effectiveness, the mitigation benefit length and the justification for the benefit length. The mitigation effectiveness workpapers are included as part of the workpapers for each RAMP risk.

4. Risk Spend Efficiency

Risk Spend Efficiency is a metric for representing the benefit to cost ratio of a mitigation, where benefit is described in terms of risk reduction. The S-MAP Settlement Decision states that RSE should be calculated by dividing the mitigation risk reduction benefit by the mitigation cost estimate. Further, the values in the numerator and denominator should be present values and, for capital programs, the mitigation costs in the denominator should include incremental expenses made necessary by the capital investment.[38]

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37 D.18-12-014, p. 16 (see, 2018 S-MAP Revised Lexicon, pp. 16-19).

38 D.18-12-014, Attachment A, p. A-13, No. 25.

PG&E's RSE results shows the risk reduction achieved per 1 million dollars ($M) spent. For example, a risk event with Frequency of one event per year and Consequence of 40 million CMI has a risk score of 20.[39] If a mitigation that costs $10 million reduces the Frequency of this risk event by 50 percent (from 1 event per year to 0.5 events per year), then then risk reduction (the difference between pre- and post-mitigation scores) is 10 and RSE is 1.[40]

When the benefit of a mitigation lasts more than one year, risk reduction is aggregated by the present value of risk reduction over the benefit years and the cost is aggregated as the present value of the costs over the spend years. Equation 2 shows the RSE calculation:

$$RSE = \frac{\text{NPV(Pre-mitigation Risk Scores)} - \text{NPV(post-mitigation Risk Scores)}}{\text{NPV(Program Costs)}}$$

Where:

- NPV (Risk Scores) and NPV (Program Costs) are the Net Present Value of the Risk Score and Program Costs.

The following sections discuss how PG&E has implemented the S-MAP Settlement Decision requirements for calculating RSE.

a. Discounting

As noted above, in compliance with the S-MAP Settlement Decision, PG&E shows the numerator and denominator of the RSE as present values.[41] PG&E uses a single discount rate, its After Tax Weighted Average Cost of Capital (ATWACC) to calculate the present value of all future costs and attributes. The base year for all discounting is 2020.

PG&E focused on two core principles when discounting:

1) Costs and benefits occurring over different time periods should be assessed on an equal basis. Principle 1 implies a non-zero discount rate for costs to account for the time value of money.

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39 Risk Score = Frequency x CoRE = Frequency (1) * Scaler (1000) * Attribute Weight (50%) * Scaled Unit (0.1) = 50.

40 Risk Reduction = Pre-mitigation Risk Score (50) – Post-mitigation Risk Score (25) = 25. RSE = Risk Reduction / Cost = 25/ 25M = 1 /$M spend.

41 D.18-12-014, Attachment A, p. A-13, No. 25.

2) All else being equal, RSEs should not change if both costs and mitigations are offset by a period of time.[42]

To achieve Principle 2, the discount rate for Attributes (i.e., in the numerator of the RSE) must not only be the same across all Attributes but also must be the same as the discount rate for costs (i.e., the denominator). The ATWACC was derived as follows:

TABLE 3-6
2020 AFTER TAX WEIGHTED AVERAGE COST OF CAPITAL CALCULATION

Line No.	Component	Weight	Cost of Capital (%)	WACC		After Tax WACC
1	Debt	48%	5.2	2.5	x (1 - tax rate)	1.8
2	Common Stock	52%	10.3	5.3		5.3
3						7.1

Note: The ATWACC used in the risk model is based on PG&E's cost of capital as of the June 30, 2020 filing date for the RAMP. On April 22, 2019 PG&E filed its Cost of Capital Application (A.19-04-015) for TY 2020. When a decision is issued in that proceeding, PG&E will make updates to its risk model as required.

This discount rate was determined solely based on the Principles and considerations above. Therefore, it is only valid in the context of calculating RSEs in this RAMP Report and should not be extended to other applications without further consideration.

b. Mitigation and Control Program Mitigation Costs

The basis of the program costs used to calculate the RSE are high level capital and expense cost estimates developed by the RAMP risk teams. PG&E used the best available information when calculating and

[42] As an example of why Principle 2 is necessary, consider a program that starts immediately and runs for a set number of years, with costs only incurred during that period. All else being equal, the program should have the same RSE if it started one year later, otherwise one could simply defer or expedite the work to increase the RSE score with no fundamental improvement in the program.

estimating the costs associated with each mitigation. These costs are included in the workpapers supporting this RAMP report.[43]

Because PG&E's GRC forecasting process is still in the early stages, the mitigation forecast costs to be included in the 2023 GRC may be different from the estimates included in this RAMP Report, including potential changes as a result of SPD and intervenor feedback in this proceeding.

c. Treatment of Capital Costs

To account for the incremental expenses associated with the capital investments such as depreciation and return on equity over the book life of an asset, PG&E is considering using an estimated Revenue Requirement associated with capital spend. Using the Revenue Requirement to calculate NPV would allow for a direct comparison between the RSEs for capital programs and the RSEs for expense programs by normalizing the risk reduction per dollar spent. Using an estimated revenue requirement will lead to lower RSEs for capital programs because the revenue costs will be included. PG&E would like SPD's and intervenor feedback on this approach and suggests that this issue should be considered in the forthcoming S-MAP rulemaking.

d. Pre-Mitigation and Post-Mitigation Risk Scores

Pursuant to the S-MAP Settlement Decision, PG&E calculated pre- and post-mitigation risk scores for each year that proposed mitigations are in effect.[44]

For this 2020 RAMP, PG&E defines the different periods as:

- Pre-mitigation: For programs planned for the GRC period (2023-2026) PG&E calculates a pre-mitigation program score that accounts for the benefits from any mitigations that are planned for 2020–2022.

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43 Each RAMP risk chapter (Chapters 7 to 18) and the Cross-Cutting Factor chapter (Chapter 20) includes cost tables and supporting financial workpapers that show the costs from 2020 through 2026 used to develop the RSE.

44 D.18-12-014, Attachment A, p. A-11, No. 13.

- 2023 TY Baseline: PG&E's upcoming GRC TY.
- Post-Mitigation: The benefits from proposed mitigations for the 2023-2026 GRC period are accounted for in the Post-mitigation Risk Scores.

e. Risk Reduction

The Risk Reduction Score captures all the program's benefits and is not limited by the GRC time period. For example, gas pipeline replacement assumes a capital life of 80 years so the benefits are assumed to accrue over all 80 years.

Certain programs in this RAMP Report benefit multiple risks. For example: (1) PG&E proposes mitigations (e.g., Enhanced Vegetation Management) that will reduce the risk of both a Wildfire and a Failure of Distribution Overhead Asset Failure risk event; and (2) PG&E proposes a mitigation (3A and 4C Line Reclosers) that will reduce risk of both an Electric Distribution Overhead Asset Failure and a Third-Party Safety Incident.

For mitigations that benefit multiple risks, PG&E includes the impact of the mitigation in the calculation of the Risk Reduction score for each RAMP risk that benefits from the mitigation. When calculating RSE, however, in instances where a mitigation benefits more than one risk, the mitigation budget is only aligned to the primary RAMP risk event.[45] For example, the budget for the Enhanced Vegetation Management is aligned to the primary RAMP risk of Wildfire and PG&E only calculates an RSE for the risk to which the budget is aligned. This approach avoids counting a single mitigation spend twice.

Many of the cross-cutting mitigations (mitigations aligned to the cross-cutting factors) address multiple RAMP risk events. The Risk Reduction for these mitigations is calculated at the risk level and then summed across each risk. The risk reduction is presented at the cross-cutting factor level (e.g., a Risk Reduction score is provided for all

[45] The one exception is related to the Skilled and Qualified Workforce (SQWF) cross-cutting factor. The costs for implementing the SQWF mitigation is divided equally between the Failure of Electric Distribution Overhead Assets risk event and the Failure of Electric Distribution Network Assets risk event.

Records and Information Management mitigations combined) and then allocated to each RAMP risk the cross-cutting factor impacts.

Some mitigations in the RAMP risk portfolios also benefit risks included as Other Safety Risks (Chapter 19) and/or additional PG&E risks not included in this RAMP Report. PG&E considers these mitigations' risk reduction value for the RAMP risks only.

The S-MAP Settlement Decision states that utilities should provide the pre- and post-mitigation values for the effects of a mitigation at the tranche level.[46] PG&E provides pre- and post-mitigation values for each RAMP risk at the tranche level in supporting workpapers.[47]

f. Tranche-Level RSE

The S-MAP Settlement Decision states that Utilities should provide RSEs at the tranche level. PG&E provides RSEs at the tranche level for each risk in supporting workpapers.[48]

To calculate tranche-level RSEs, the risk model requires a tranche-level cost estimate for each mitigation and control. The risk owners provided the mitigation and/or control costs at the tranche level.[49] This approach is consistent with the S-MAP Settlement Decision which requires RSEs to reflect the full set of benefits that result from the incurred costs.[50]

Many of the cross-cutting mitigations address multiple RAMP risk events, but the costs cannot be meaningfully separated or allocated. Therefore, the RSEs for the cross-cutting mitigations are provided at the cross-cutting factor level (e.g., one RSE is provided for all Records and Information Management mitigations combined).

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46 D.18-12-014, Attachment A, p. A-12, No. 16.

47 See WP 3-5.

48 See WP 3-19.

49 The modeling workpaper input files show the tranche-level costs. Modeling input files will be provided July 17, 2020.

50 D.18-12-014, Attachment A, p. A-13, No. 25.

g. Foundational Mitigations

PG&E defines foundational mitigations as those programs that support multiple mitigations that reduce risk, but do not reduce the risk themselves. PG&E does not allocate the costs of foundational mitigations among the mitigations they support because the costs cannot be allocated in a meaningful way.

Foundational mitigations are, by definition, assigned an RSE of 0 and marked as such in the analyses.

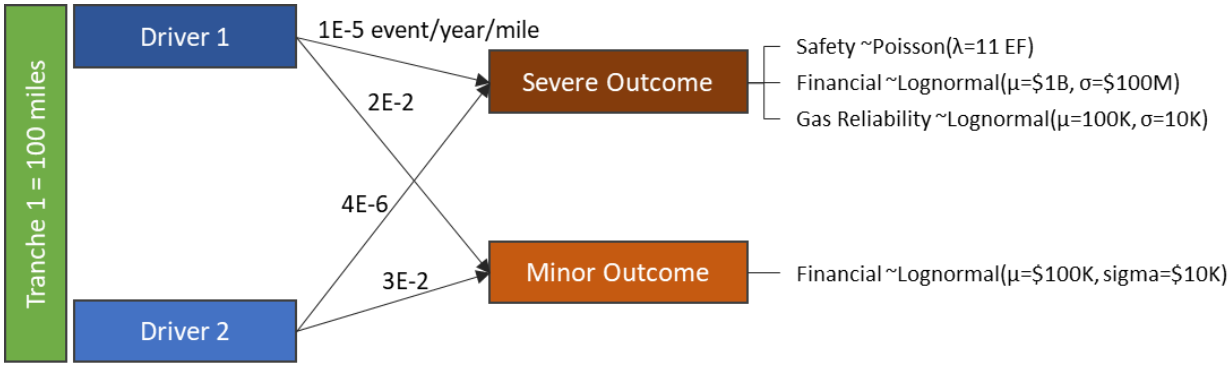
Certain actions that could be considered foundational mitigations are necessary to support a *single* mitigation program. PG&E includes the costs for these actions as part of the cost of the mitigation program they enable and does not consider them foundational mitigations.

5. Risk Analysis Example: MAVF, Risk Score, Risk Reduction, and RSE

This section walks through an example of how a simple Bow Tie model (shown in Figure 3-7 below) is used to compute Risk Spend Efficiency values for two proposed mitigations and addresses:

a) LoRE;
b) CoRE;
c) Expected Value from simulated CoRE;
d) Risk Score;
e) Risk Reduction; and
f) Risk-Spend Efficiency.

FIGURE 3-7
EXAMPLE BOW TIE INPUT ASSUMPTIONS



Note: Poisson and Lognormal refer to the parametric probability distributions used to model the outcome of the risk event.

The example Bow Tie in Figure 3-7 includes:

- Two drivers – Driver 1 and Driver 2;
- Two Outcomes – Minor and Severe;
- One tranche, Tranche 1, defined by an exposure of 100 miles of an asset;
- The risk event is characterized by potential Safety, Gas Reliability, and Financial consequences;
- The Minor outcome has only Financial consequences; and
- The Severe outcome has greater Financial consequences, as well as Safety and Reliability impacts.

The two distinct outcomes for this single risk event, allows the model to capture the low frequency high consequence outcome and the high frequency low consequence outcome, each of which have uncertainty regarding the magnitude of the consequences.

a. Likelihood of Risk Event

Likelihood of Risk Event is calculated per tranche-outcome-driver. The example Bow Tie in Figure 3-7, with one tranche, two drivers, and two Outcomes requires (1*2*2 = 4) four frequency values.

Where there is more than one tranche, PG&E calculates as many sets of tranche-driver-outcome frequencies and Outcome Attribute distributions as there are tranches. Risk Events that are presented in this RAMP report include tens or hundreds of frequency values per Risk Event.

For the sample Bow Tie, the LoRE occurring per year, per unit of exposure (LoRE) is the sum of the four frequencies shown in Table 3-7.

TABLE 3-7
SAMPLE BOW TIE: SUMMARY OF LORE BY DRIVER, OUTCOME AND RISK EVENT

Line No.	Calculation	Minor Outcome	Severe Outcome	LoRE by Driver	Percent of Frequency by Driver
1	LoRE for Driver 1	0.02	0.00001	0.02001	40%
2	LoRE for Driver 2	0.03	0.000004	0.030004	60%
3	LoRE (/yr/mile) =	0.05	1.4E-05		
4	Freq (#/year) =	5	0.0014		
5	% of Freq =	99.97%	0.03%		100%

- LoRE for each Driver = Minor Outcome + Severe Outcome;
- LoRE per year per mile = LoRE for Driver 1 + LoRE for Driver 2;
- Frequency (number of events per year) = LoRE per year per mile x 100 (exposure);[51] and,
- Percent of Frequency = Frequency of Each Outcome / Total Frequency – For example, 5/(5+0.0014) = 99.97%

Therefore, the model expects 0.050014 events per year per mile, which is equivalent to a probability of 0.050014 that the event will happen each year on a given mile of exposure.

Given 100 miles of exposure on the tranche, the risk event frequency is:

Frequency = Exposure x LoRE = 100 x 0.050014 = 5.0014 events per year

Of these 5.0014 events:

- 99.97% of the time the outcome is Minor; and
- 0.03% of the time (1 in 714 years) the outcome is Severe.

b. Consequence of Risk Event (CoRE) for one Trial

Risk event consequences are calculated per tranche-outcome-attribute combination. The Severe Outcome is illustrated in this example given its complexity relative to the Minor Outcome.

The Severe Outcome has Safety, Reliability, and Financial attributes, each defined using a parametric probability distribution (two Lognormal, one Poisson). This example of the CoRE calculation using the MAVF assumes that these attributes are deterministic (the model does not include elements of randomness and the results will be the same every time you run the model) to simplify the application of the MAVF. A description of the probabilistic case (i.e., a model that includes elements of randomness and presents results that vary each time you run the model) follows in Section D.5.c, CoRE as Expected Value.

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51 The value “100” is used here because the Tranche is defined as 100 miles and the LoRE is measured per mile.

The Consequences of a Risk Event in Natural Units for the Severe Outcome are listed in Column A of Table 3-8. The step-by-step calculation below computes all quantities for the Safety Attribute to illustrate the Safety CoRE calculation. Identical steps are performed for each of the other Attributes.

TABLE 3-8
SAMPLE BOW TIE: MAVF DATA FOR SEVERE OUTCOME
ASSUMING DETERMINISTIC CONSEQUENCE

		Column			
		A	B	C	D
Line No.	Attribute	Consequence of Risk Event in Natural Unit	Normalized Natural Unit (0-1)	Scaled Unit	Attribute CoRE
1	Safety	11 EF	0.11	6.1	3,027
2	Gas Reliability	100K Customers	0.133	8.5	426
3	Financial	$1B	0.2	15.6	3,889

Calculating the Safety CoRE

Column A has values in Natural Units for each Attributes. The expected values of the distributions are assumed to be a deterministic consequence. The Safety consequence is 11 EFs.

Column B is an intermediate step applying the scaling function characterized in Equation 1 (Figure 3-4), specifically calculating parameter *r*. It results from normalizing the Natural Unit values in Column A using the Attribute Ranges in Table 3-2. This step determines which scaling function Region the Natural Units fall within.

Normalized Unit (Safety) = Natural Unit (Safety)/(Upper Bound – Lower Bound)

= 11 / (100 – 0) = 0.11

Column C shows the results of applying the scaling function to the Natural Unit. Given Normalized Natural Units, *r*, the scaling function returns Scaled Units.[52] The Safety outcome is “catastrophic”, r = 0.11 >

[52] If a linear scaling function had been used, Column C would simply be 100*Column B.

R_2, so the equation corresponding to Region 3 from Equation 1 and Figure 3-3 is used ($S_2 = 5$, $R_2 = 0.1$).

$$\text{Scaled Unit (Safety)} = \frac{100 - S_2}{1.0 - R_2}(\text{Normalized Unit} - R_2) + S_2$$
$$= \frac{100 - 5}{1.0 - 0.1}(0.11 - 0.1) + 5 = 6.1$$

Column D is the Attribute CoRE, calculated as scaled units multiplied by the appropriate weight x a Scaler of 1000. The Attribute weights are as defined in Table 3-4. The Safety CoRE is calculated as:

Safety CoRE = Scaler x Safety Weight x Scaled Unit (Safety)

$$= 1000 \times 0.5 \times 6.1 = 3{,}027$$

Finally, all Attribute-level CoREs (Column D) are summed to compute the CoRE at the risk level:

CoRE = Safety CoRE + Gas Reliability CoRE + Financial CoRE

$$= 3027 + 426 + 3889 = 7{,}343$$

Following the same steps, the CoRE of the Minor Outcome is 0.05.

c. CoRE as Expected Value

PG&E's risk model simulates the Natural Units for relevant tranche-outcome-attribute combinations. Table 3-9 below shows the simulated natural unit values for all Severe Outcome attributes for 10 trials,[53] based on the calculations described in Section D.5.b above.

[53] PG&E's model runs 10,000 trials per distribution.

TABLE 3-9
SAMPLE BOW TIE: SIMULATED SEVERE OUTCOMES VALUES IN NATURAL UNITS AND ATTRIBUTE CORE CALCULATIONS[(a)]

Trial	Safety				Reliability				Financial			
	Sim Natural Unit (EF)	Normalized	Scaled	Total CoRE	Sim Natural Unit (1k Cust)	Normalized	Scaled	Total CoRE	Sim Natural Unit ($M)	Normalized	Scaled	Total CoRE
1	5	0.05	1.3	646	84	0.11	6.3	315	871	0.17	12.8	3,207
2	8	0,08	3.2	1,611	86	0.12	6,6	330	871	0.17	12.8	3,209
3	8	0.08	3.2	1,611	91	0.12	7.2	362	982	0.20	15.2	3,791
4	10	0.10	5.0	2,503	96	0.13	8.0	400	987	0.20	15.3	3,819
5	12	0.12	7.1	3,556	97	0.13	8.0	401	1,006	0.20	15.7	3,923
6	12	0.12	7.1	3,556	104	0.13	8.1	406	1,028	0.21	16.2	4,039
7	13	0.13	8.2	4,083	104	0.14	9.1	453	1,031	0.21	16.2	4,053
8	14	0.14	9.2	4,611	108	0.14	9.1	456	1,051	0.21	16.6	4,158
9	14	0.14	9.2	4,611	108	0.14	9.6	481	1,119	0.22	18.1	4,517
10	15	0.15	10.3	5,139	109	0.14	9.7	486	1,134	0.23	18.4	4,594
11	**Safety CoRE 3,193**				**Reliability CoRE 409**				**Financial CoRE 3,931**			
Sum of Attribute Values: 7,533												

(a) The Attribute CoRE is the average of the CoRE per trial for that Attribute.

The additional step required to compute the Attribute CoRE (compared to the steps required to calculate the CoRE for one trial described in Section D.5.b) is to take the average of all Trial CoRE values.

Therefore, the CoRE for the Severe Outcome is the average sum of the three Attribute CoRE values: 3,193 + 409 + 3,931 = 7,533.

The CoRE using the probabilistic values is greater than the CoRE computed using deterministic values because of the non-linear scaling function, which places greater weight on those trials having the least favorable outcomes (e.g., Row 10 in Table 3-9).

Following the identical process, PG&E calculated the CoRE for the Minor Outcome (based only on the Financial Attribute because it is the only outcome of a minor event). The Minor Outcome CoRE is 0.054.

TABLE 3-10
SAMPLE BOW TIE: CORE PER OUTCOME

Line No.	Outcome	CoRE
1	Severe	7,533
2	Minor	0.054

Using these outcome-based CoRE values, the CoRE at the risk-level is calculated as a weighted sum of CoRE based on the frequency percentage of each outcome.

CoRE = % Freq (Minor Outcome) x CoRE (Minor Outcome)
+ % Freq (Severe Outcome) x CoRE (Severe Outcome)

CoRE = 0.03% (Table 3-7) x 7,533 (Table 3-9) + 99.97% (Table 3-7) x 0.054 (Table 3-10) = 2.2

d. Risk Score

The Risk Score is computed at the tranche-outcome level. Given a single tranche for this example risk, the risk scores per outcome are:

Risk Score (Minor Outcome) = Frequency (Minor Outcome) x CoRE (Minor Outcome)
= 5 (Table 3-7) x 0.054 (Table 3-10) = 0.27

Risk Score (Severe Outcome) = Frequency (Severe Outcome) x CoRE (Severe Outcome)
= 0.0014 (Table 3-7) x 7,533 (Table 3-9) = 10.55

Risk Score = Risk Score (Minor Outcome) + Risk Score (Severe Outcome)
= 0.27 + 10.55 = 10.82

The sample risk Bow Tie, Figure 3-8 below, shows that the Severe Outcome contributes 97 percent of the total risk though it represents only 0.03 percent of the frequency of a risk event.

FIGURE 3-8
SAMPLE BOW TIE: EXAMPLE RISK EVENT SUMMARY

e. Risk Reduction Score

To calculate the Risk Reduction score PG&E uses data supplied by the RAMP risk teams that outline the effectiveness of the proposed mitigation and the duration of the mitigation benefit.

Table 3-11 is information for two mitigations used in the example calculation.

TABLE 3-11
SAMPLE BOW TIE: CHARACTERISTICS FOR MITIGATION 1 AND MITIGATION 2

Line No.	Target	Effectiveness Percentage	Scope	Benefit Duration	Effectiveness Degradation
1	Frequency of Drivers 1 and 2	20%	17 miles in Year 1	4 Years	20% annually
2	Safety Consequences of Severe Outcome	10%	100 miles each year from Year 1 to Year 4	1 Year	0%

1) Mitigation 1 – Program Frequency

Proposed mitigation M1 targets all risk drivers for the risk event and is 20 percent effective at reducing event frequency. Effectiveness of M1 is provided per unit of exposure to which the mitigation is applied. Using the scope and effectiveness of the mitigations, the model calculates the average effectiveness at the tranche level:

Average effectiveness = Effectiveness x Scope / Tranche Exposure
= 20% x 17 miles/ 100 miles = 3.4%

Because M1 affects all risk drivers equally applied to the single risk tranche, Risk Reduction is equal to 3.4% of the Risk Score (10.82 x 0.034 = 0.37). Risk Reduction can also be calculated as:

Pre-Mitigation Risk Score = 10.82 (Section D.5.d)
Post-Mitigation Risk Score = (1 – 3.4%) x 10.82 = 10.45
Risk Reduction Score (M1) = Pre-Mitigation Risk Score – Post-Mitigation Risk Score
= 10.82 – 10.45 = 0.37

2) Mitigation 2 – Consequence Mitigation

Proposed mitigation M2 reduces the magnitude of the Safety consequence by 10 percent, but only for the Severe Outcome. The mitigation effectiveness is applied to the entire project scope, so the average effectiveness at a tranche level is the same as the effectiveness at a program exposure level:

Average effectiveness = Effectiveness x Scope / Tranche Exposure
= 10% x 100 miles / 100 miles = 10%

The average effectiveness is applied to the simulated Natural Units (Table 3-9, Severe Outcomes Values in Natural Units) to determine the post-mitigation consequence as shown in Table 3-12 below.

TABLE 3-12
SAMPLE BOW TIE: SIMULATED SEVERE OUTCOME VALUES IN MITIGATED NATURAL UNITS AND ATTRIBUTE CORE CALCULATIONS

Trial	Pre-Mitigation Consequence in Natural Units (EF)[a]	Post-Mitigation Consequence in Natural Units (EF)[b]	Normalized	Scaled	Trial CoRE
1	5	4.5	0.045	1.1	528
2	8	7.2	0.072	2.6	1,310
3	8	7.2	0.072	2.6	1,310
4	10	9.0	0.090	4.1	2,032
5	12	10.8	0.108	5.8	2,922
6	12	10.8	0.108	5.8	2,922
7	13	11.7	0.117	6.8	3,397
8	14	12.6	0.126	7.7	3,872
9	14	12.6	0.126	7.7	3,872
10	15	13.5	0.135	8.7	4,347
11				Safety CoRE	2,651

(a) Values from Table 3-9, Severe Outcomes Values in Natural Units.

(b) Reflects value after 10 percent effectiveness applied to the Pre-Mitigation Consequence in Natural Units.

Mitigation M2 reduces Safety consequence by 10 percent but the Safety CoRE is reduced by 17 percent—from 3,193 (Table 3-9) to 2,651—as a result of the non-linear scaling function. Risk Reduction is calculated as follows:

Pre-Mitigation Risk Score = 10.82 (Section D.5.d)

Post-Mitigation CoRE (Severe Outcome) =
2,651 (Table 3-12) + 409 (Table 3-9) + 3,931 (Table 3-9) = 6,991

Post-Mitigation Risk Score (Severe Outcome)
= Frequency (Severe Outcome) x Post-Mitigation CoRE (Severe Outcome)
= 0.0014 (Table 3-7) x 6,991 = 9.78

Post-Mitigation Risk Score =
Post-Mitigation Risk Score (Severe Outcome) + (Post-Mitigation) Risk Score (Minor Outcome)
= 9.78 + 0.27 (Section D.5.d) = 10.05

Risk Reduction Score (M2) = Pre-Mitigation Risk Score - Post-Mitigation Risk Score

= 10.82 (Section D.5.d) – 10.05 = 0.77

TABLE 3-13
SAMPLE BOW TIE: RISK REDUCTION SCORE BY MITIGATION

Line No.	Mitigation	Risk Reduction Score	Post-Mitigation Risk Score
1	M1	0.37	10.45
2	M2	0.77	10.05

f. Risk Spend Efficiency

Risk Spend Efficiency (Equation 2) is the risk reduction per dollar spent:

$$RSE = \frac{\text{NPV(Pre-mitigation Risk Scores)} - \text{NPV(post-mitigation Risk Scores)}}{\text{NPV(Program Costs)}}$$

PG&E calculated the RSEs shown in Table 3-14 for the two sample mitigations using: the risk reduction scores in Table 3-13; the discounting factor discussed in Section C.4.a to calculate the NPV; and sample program costs

TABLE 3-14
SAMPLE BOW TIE: RISK REDUCTION SCORE BY MITIGATION

Line No.	Risk Reduction Score and Cost by Mitigation	Year 1	Year 2	Year 3	Year 4	NPV
1	Risk Reduction Score (M1)	0.37	0.30	0.24	0.19	1.01
2	Risk Reduction Score (M2)	0.77	0.77	0.77	0.77	2.79
3	M1 Program Cost ($M – Capital)	$2.00	–	–	–	2.00
4	M2 Program Cost ($M – Expense)	$0.50	$0.50	$0.50	$0.50	1.81

RSE (M1) = NPV of Risk Reduction Score (M1) / NPV of Program Costs (M1)

= 1.01 / 2.00 = 0.50

RSE (M1) = NPV of Risk Reduction Score (M2) / NPV of Program Costs (M2)

= 2.79 / 1.81 = 1.54

E. Workpapers Supporting PG&E's RAMP Risk Models

The S-MAP Settlement Decision requires that PG&E provide in its RAMP Report a ranking of all RAMP mitigations by RSE.[54] This ranking is provided in supporting workpapers (WP 3-1).

A list of the 12 RAMP risks with the final safety risk score and final total risk score for each is also included in workpapers (WP 3-3).

PG&E has developed workpapers supporting each of its 12 RAMP risk models and a risk model User Guide. The workpapers consist of a risk model input file and a risk model output (Bow Tie) file.[55]

- User Guide – The User Guide provides information about how to input data into the files in order to run the risk model. It also provides calculations, distributions and other information so users can better understand the different elements driving the risk model.
- Source Documents Index and Source Documents – The source documents index lists all of the data used in the risk model. It includes a reference to the source file that is available in soft copy and/or a link to publicly available information. The index number for each file listed on the source document index is also used in the risk model to reference the data used in the model.
- Input Files – This file includes the inputs into the risk model for each of the 12 RAMP risks. It lists the drivers, sub-drivers, tranches and consequences for each risk. Modeling information includes frequency inputs by sub-driver, frequency multipliers, consequence multipliers, program exposure, program costs, program effectiveness on consequences and frequencies, and escalation methods. Input files will be made available in soft copy.
- Bow Tie File – This file includes the outputs from the risk model for each of the 12 RAMP risks. It includes the Bow Tie and Consequence Table graphics included in each RAMP risk chapter (Chapters 7 to 18), the risk

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54 D.18-12-014, Attachment A, p. A-14, No. 26.

55 Modeling workpapers will be submitted on July 17, 2020.

scores, RSE, and risk reduction score for each mitigation and the RSE and risk reduction score for each alternative mitigation plan. In addition, the file includes detailed output for driver frequency, outcome frequency, tranche level exposure, risk score by outcome, risk score by tranche, risk score by outcome by attribute, and driver contribution to risk scores. Bow Tie files will be made available in soft copy.

PG&E has prepared mitigation effectiveness workpapers that describe each mitigation program, the effectiveness of each program, the justification for the effectiveness percentage, the mitigation benefit duration, and reason for selecting that duration, and the annual degradation rate of effectiveness. These workpapers are part of the modeling source documents package that will be provided following the RAMP Report. PG&E is also providing a courtesy copy of these workpapers with the RAMP Report.[56]

F. Response to TURN's Feedback Regarding PG&E's 2020 RAMP Methodology

PG&E presented our risk modeling methodology at public workshop hosted by the SPD on January 13, 2020 and February 4, 2020. We received feedback from The Utility Reform Network (TURN) about our RAMP risk modeling methodology and other RAMP-related topics in a letter dated February 19, 2020.[57] This section addresses modeling-related concerns raised by TURN, following the outline of TURN's February 19, 2020 letter. Other concerns raised by TURN are addressed elsewhere in this Report and in the responsive letter that PG&E sent TURN on February 25, 2020.[58]

Concerns with PG&E's MAVF

TURN states that the MAVF tool is fundamental to accurately and comprehensively capture all the pre- and post-mitigation consequences of risk events and thus it must be well-designed in order to yield reliable results.[59]

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56 See workpapers starting at WP 3-6.

57 Legal Director Thomas J. Long, TURN, letter to Tessa Carlberg and PG&E 2020 RAMP Team, February 19, 2020. (TURN's February 19, 2020 Letter). A copy of the letter is included as WP 3-9.

58 Senior Director Janaize Markland, PG&E Enterprise & Operational Risk & Insurance, letter to Legal Director Thomas J. Long, TURN, February 25, 2020 (PG&E's February 25, 2020 letter).

59 TURN's February 19, 2020 Letter, p. 2.

TURN then describes four specific areas of concern with PG&E's MAVF, each of which PG&E addresses below.

1. Scaling Function

TURN raises several issues with respect to the scaling function used in PG&E's MAVF to convert attribute levels from natural units to scaled units. In general, TURN's criticisms stem from its opinion that PG&E should use a linear scaling function instead of a non-linear scaling function.[60]

PG&E and TURN disagree on this issue. As explained in Section B above, PG&E's risk management philosophy is risk-averse, i.e., PG&E is focused on reducing the risk of catastrophic (low frequency, high consequence) events. A linear scaling function yields a risk score that effectively treats all outcomes as "average." By contrast, a non-linear function is sensitive to the distribution of consequences, not just the mean, which allows PG&E to better understand and manage the tail-risk associated with catastrophic events.

PG&E responds to TURN's specific concerns about the scaling function below.

a. TURN Issue 1a: Scaling Function for Financial Consequences Attribute

TURN states that PG&E's use of a non-linear scaling function for financial consequences violates: (1) the concept that the value of one dollar is always one dollar; and, (2) the idea that financial benefits should be additive because "it permits the financial value of a single project to change if that project is divided arbitrarily into two or more parts."[61]

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60 TURN's February 19, 2020 Letter, p. 2, Item 1.a.

61 TURN's February 19, 2020 Letter, p. 2, Item 1.a.

PG&E's Response:

While in the abstract one dollar is the same as another, the purpose of the MAVF is to measure Risk (in Scaled Units), not dollars. The MAVF measures the effect on PG&E and our customers of losing a certain amount of money. In economics, this is expressed as utility theory, which is based on the idea that individuals assign different levels of satisfaction values to the original monetary values and use the utility values, not direct monetary values, when making decisions. A dollar when an individual has two dollars can be valued more than a dollar when the individual has 100 dollars. The utility function translates monetary values into the amount of satisfaction and its curvature is different by the preference of a decision maker. Risk-averse decision makers have concave utility function while risk-seeking decision makers have convex utility functions.[62]

PG&E treats the MAVF scaling function as a form of a utility function applied to a consequence from a risk event. PG&E's non-linear scaling function has non-decreasing slope within the Attribute Range that is, in principle, consistent with a risk-averse decision maker.[63] As permitted by MAVF Principle 5, PG&E captures its aversion to catastrophic outcomes through the use of a non-linear scaling function.[64]

TURN's concern that use of a non-linear function could permit the financial value of a single project to change if that project is divided arbitrarily into two or more parts is unfounded. The financial consequence attribute measures the financial consequences of *risk events*, not projects. Consistent with the S-MAP Settlement Decision, PG&E has defined risk events in terms of logical units such as fire

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62 Eeckhoudt et al., Economic and Financial Decisions Under Risk (2005), Chapter 1.

63 Traditional utility functions measure the amount of satisfaction, well-being, etc. from *receiving* amounts of an attribute (e.g., dollars), and risk-aversion is expressed by a concave utility function. The MAVF, however, measures the loss in utility from *losses* of an attribute, so a risk-averse individual would have a convex MAVF.

64 D.18-12-014, Attachment A, pp. A-5 to A-6, No. 6.

ignitions or outages.[65] PG&E has not "arbitrarily" divided (or combined) risk events in a way that would change risk scores. While PG&E would consider any input TURN might have about how to improve risk event definition, the suggestion that PG&E hypothetically could define the same risk events in multiple ways (leading to different risk scores) is not a good reason to force PG&E to use a linear scaling function that does not capture our aversion to catastrophic risk.

b. TURN Issue 1b: Scaling Function for Safety Consequences Attribute

TURN states that PG&E's non-linear scaling function for the safety attribute indicates that the value of reducing equivalent deaths from 1 to zero is less than one-tenth as much as reducing the equivalent deaths from 100 to 99. TURN argues that this is both counterintuitive and inconsistent with industry-wide practice and that PG&E's non-linear scaling function should be modified.[66]

PG&E's Response:

As discussed in Section B, PG&E's risk management focus is on reducing catastrophic events with potentially extreme consequences because of the disparate impact that a single catastrophic even can have relative to multiple lower consequence events. PG&E's use of a non-linear function allows it to understand and manage the tail risk of catastrophic events. In addition, PG&E believes that 10 different

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65 The S-Map Settlement Decision is clear about how likelihoods and consequences should be defined and does not provide discretion for arbitrary divisions of risk events and consequences. Under Step 2A, Row No 10 of Appendix A, p. A-8, it requires "[f]or each enterprise risk, the utility will use actual results, available and appropriate data … and/or Subject Matter Experts (SMEs) to identify potential consequences of the risk event … ." Similarly at Row No 11, p. A-11, it requires "[f]or each enterprise risk, the utility will use actual results and/or SME input … ." Under Global Items, p. A-17, Row No 29, it requires "[t]he sources of inputs should be clearly specified. When SME judgment is used, the process that the SMEs undertook to provide their judgement should be described." Further on, it states, "[t]he methodologies used by the utility should be mathematically correct and logically sound." (Underscore added.) In D.18-12-014, the CPUC also agreed that emphasis should be placed on developing comparable risk scores (which would require consistent risk event definitions) across utilities. PG&E looks forward to participation in this topic in a future OIR.

66 TURN's February 19, 2020 Letter, pp. 2-3, Item 1.b.

non-catastrophic events are unlikely to result in the same level of impact as one catastrophic event.

c. TURN Issue 1c: Statistical Value of Life Given by Weights and Attribute Ranges

TURN states that the implied Value of Statistical Life (VSL) given by the weights and the attribute ranges for safety and financial impacts is $100 million which is ten times higher than statistical values used by the U.S. Environmental Protection Agency to evaluate health risk and the U.S. Dept. of Transportation to evaluate vehicle safety features. TURN is concerned that PG&E's use of this higher value may result in skewing the ranking of different risks and misallocating risk management dollars.[67]

PG&E's Response:

To a large extent, the implied statistical value of a life that TURN identifies is a result of required elements of the MAVF calculation process, particularly the emphasis on safety.

PG&E's MAVF is "a tool for combining all potential consequences of the occurrence of a risk event, and creat[ing] a single measurement of value."[68]

MAVF Principle 2 requires that each lower-level Attribute of the MAVF (i.e., safety, reliability, financial impact) has its own minimum and maximum range expressed in natural units that are observable during ordinary operations and as a CoRE.[69] The S-MAP Settlement Decision defines the low and high end of the range of natural units to be the smallest and largest observable value from a risk event, respectively.[70] Consistent with this definition, PG&E set the ranges of the safety and financial consequence Attributes based on historical events and plausible high-consequence scenarios. For the safety Attribute, the high end of the range was based on EFs from the Camp Fire, rounded up

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67 TURN's February 19, 2020 Letter, p. 3, Item 1.c.

68 D.18-12-014, Attachment A, p. A-3.

69 D.18-12-014, Attachment A, p. A-5, No. 3.

70 D.18-12-014, Attachment A, p. A-3.

to 100. For the financial Attribute, the high end of the range, $5 billion, represents a financial loss commensurate with a 2000-2001 Energy Crisis-type event, recognizing that shareholder losses are not considered.

Consistent with the S-MAP Settlement Decision, PG&E assigned Attribute weights in the MAVF based on the relative value of moving each Attribute from its least desirable to its most desirable level, considering the entire range of the Attribute.[71] Attribute weights reflect the relative importance of moving the safety outcomes from the least to the most desirable level as compared to moving financial outcomes from the least to the most desirable levels. PG&E's MAVF combines the Safety, Electric Reliability, Gas Reliability, and Financial attribute consequences of a risk event using the 50 percent, 20 percent, 5 percent and 25 percent weights, respectively, so that safety consequences throughout the attribute range are given twice the weight of financial consequences. This weights 100 EFs (the high end of the Safety consequence range) as comparable to $10 billion (which is twice the $5 billion high end of the Financial consequence range). This relationship could be adjusted by changing the relative weights of the Safety and Financial attributes, but the S-MAP Settlement Decision requires that the safety attribute be set at 40 percent or higher, so any adjustment would not reduce the implied VSL to published values.[72] As it stands, the S-MAP Settlement Decision framework is not directly compatible with VSL. Furthermore, PG&E believes the 50 percent weighting of the safety Attribute provides an appropriate focus on safety.

2. Number of Attributes

TURN believes that there appear to be too few attributes in PG&E's MAVF and strongly doubts that the four attributes considered (Safety, Electric Reliability, Gas Reliability and Financial) cover all the reasons for

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71 D.18-12-014, Attachment A, p. A-6, No. 7.

72 D.18-12-014, p. 67, Ordering Paragraph (OP) 2. Based on the ranges PG&E established, the lowest VSL that could be achieved is approximately $33.3 million, by eliminating the Reliability Attributes, reducing Safety to 40 percent, and assigning 60 percent to the Financial Attribute.

engaging in risk mitigation. TURN claims that PG&E failed to take customer satisfaction into account by failing to include a customer satisfaction attribute.[73]

PG&E's Response:

The four attributes PG&E includes in its risk model incorporate the essential elements required to deliver safe, reliable, and affordable service to our customers. Providing safe, reliable and affordable service is the foundation of customer satisfaction, and PG&E does not believe that adding a customer satisfaction attribute would significantly change its risk analysis.

3. Risk Aversion

TURN states that one of PG&E's motivations for non-linear scaling functions is "risk aversion," which TURN claims is inconsistent with long-standing economic principles. TURN believes that risk-averse behavior in the face of uncertainty does not apply with multi-attribute scaling functions because the purpose of scaling functions is to reflect known tradeoffs and states that PG&E's MAVF reflects PG&E's preference for reductions in worst-case outcomes over equivalent reductions in other, non-worst-case outcomes.[74]

PG&E's Response:

PG&E has explained in Section B above why we are risk-averse, i.e., why we prefer mitigations that reduce the potential for risk events with catastrophic outcomes over mitigations that reduce a similar amount of high frequency, low consequence risk. Due to the greater potential uncertainty surrounding catastrophic events, and their potential to disrupt communities and PG&E's operations, these two types of risk reduction are not truly "equivalent." TURN claims that "risk averse behavior in the face of uncertainty doesn't apply with multi-attribute scaling functions,"[75] but MAVF Principle 5 – Scaled Units, explicitly contemplates use of scaling functions, including non-linear functions to "captur[e] aversion to extreme outcomes."

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73 TURN's February 19, 2020 Letter, p. 3 Item 2.

74 TURN's February 19, 2020 Letter, p. 4, Item 3.

75 TURN's February 19, 2020 Letter, p. 4, Item 3.

4. Initial Modeling Results

TURN writes that PG&E stated in its January 13, 2020 workshop that another motivation for the non-linear scaling function selected was that the Company did not like the initial results of its modeling, and so adjusted the scaling function to reflect Company intuition regarding the levels of different risks. As a result, PG&E may not, in fact, select the most cost-effective set of risk mitigation measures.[76] This is a misinterpretation of PG&E's workshop comments.

PG&E's Response:

PG&E's objective for its S-MAP Settlement Decision implementation, including use of a non-linear scaling function, has always been to focus on tail risk. PG&E stated this objective in the January 13, 2020 workshop. PG&E did not arbitrarily "place its thumb on the scale" to favor one risk over another.

PG&E also mentioned that it tested various scaling functions (i.e., "scales") against real-world risk events to see how they represented tail risk. PG&E tested a linear scaling function on its risk Bow Ties. The results agreed with PG&E's assumption that a linear scaling function would not did not adequately represent tail risk.

Concerns with the Calculation of RSE

5. Discount Rates

TURN writes that, at the January 13, 2020 workshop, PG&E stated that it was using three different discount rates: a zero discount rate for the Safety and Reliability attributes; a market-based discount rate for the Financial attribute; and, PG&E's utility discount rate for all program costs. TURN claims that using different discount rates is inconsistent with basic economic concepts for project evaluation.[77]

PG&E's Response:

Upon consideration PG&E agreed with TURN's feedback and has used a single discount rate for all risk model calculations.

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[76] TURN's February 19, 2020 Letter, p. 4, Item 4.

[77] TURN's February 19, 2020 Letter, p. 5, Item 5.

Failure to Account for All Consequences of Risk Events

TURN notes that under the S-MAP Settlement Decision it is critical that all consequences of a risk event be included in the analysis. TURN identifies two instances where it claims that PG&E has improperly failed to include potential consequences of a risk event in its analysis. PG&E responds to TURN's concerns below.

6. Indirect Impacts or Consequence of the Risk Event

TURN claims that PG&E ignores "indirect" impacts or consequences of risk events, which could lead to underestimating CoRE values or inaccurate RSE values. In particular, TURN notes that PG&E's risk modeling of safety consequences does not account for "death or injuries caused by the failure of electrical equipment caused by a widespread planned or unplanned outage—such as non-functioning traffic lights, breathing machines, and other medical equipment—even though these are known consequences of outages."[78] TURN believes that this may lead to inaccurate RSEs due to "the failure to consider adverse safety impacts from Planned Shutoffs."[79] TURN notes that Row 31 of the S-MAP Settlement Decision states that "SME judgment should be used if the methodology requires use of data that is not available."[80] TURN further indicates that PG&E "has subject matter experts who should be able to develop estimates of these indirect impacts [and] can also intensify its efforts to seek out data about the safety impacts of power outages."[81]

PG&E's Response:

PG&E's risk assessment only includes direct safety consequences. TURN claims that outages have known safety consequences—such as deaths or injuries due non-functioning traffic lights, breathing machines, and other medical equipment—but PG&E does not have sufficient data to determine whether these safety consequences actually materialize (or if

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78 TURN's February 19, 2020 Letter, p. 6, Item 6.

79 TURN's February 19, 2020 Letter, p. 6, Item 6.

80 TURN's February 19, 2020 Letter, p. 5, Failure to Account for All Consequences of Risk Events.

81 TURN's February 19, 2020 Letter, p. 6, Item 6.

they do, how often). Under these circumstances, PG&E believes that any estimate using SME judgment would only make PG&E's risk analysis more speculative and uncertain.

7. Excluding Safety Impacts from Outages From Third-Party Safety Incident

TURN states that PG&E's failure to include the safety impacts from outages as discussed in Item 6 above also affects the Third-Party Safety Incident risk. TURN suggests that one way to address its concern is "to distinguish between outage-related and non-outage-related outcomes on the right side of the [Bow Tie], and include potential safety consequences associated with the outage outcomes."[82]

PG&E's Response:

PG&E incorporated TURN's feedback and distinguished outage-related and non-outage-related outcomes as 'Public Interaction with Reliability Impact" and "Public Interaction." However, PG&E did not include potential safety consequences associated with the outage outcomes for the reasons responded to Item 9.

Insufficient Granularity of Analysis

TURN notes that the S-MAP Settlement Decision requires that risk analyses be disaggregated by tranches to ensure that the highest risks in the system get the requisite attention and that mitigations are not too broadly scoped. TURN is concerned that PG&E's risk analysis is not sufficiently granular.[83] PG&E responds to TURN's specific concerns below.

8. Granularity Related to the Wildfire Risk

TURN states that the Wildfire risk should have more granularity, specifically tranches that reflect asset condition, whether the asset has been upgraded, and geographic locations.[84]

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[82] TURN's February 19, 2020 Letter, p. 6, Item 7.

[83] TURN's February 19, 2020 Letter, p. 6.

[84] TURN's February 19, 2020 Letter, pp. 6-7, Item 8.

PG&E's Response:

PG&E discusses the tranches used to model Wildfire in Chapter 10, Section B.4. PG&E is continually evaluating how it defines its tranches to find the right balance between too few and too many tranches.

9. Developing Tranches to Account for Differences in Consequences Owing to Geographic Locations of Assets

TURN states that PG&E should account for differences in consequences of the occurrence of risk events owing to geographic locations, and references the Loss of Containment on a Gas Transmission Pipeline risk event.[85]

PG&E's Response:

PG&E addresses this issue in Chapter 7, Section B.4.

10. Incorporating Asset Condition when Specifying Tranches

TURN states that PG&E should incorporate asset condition when it specifies tranches of assets involved in specific risks and references the Loss of Containment on a Gas Transmission Pipeline risk event as an example.[86]

PG&E's Response:

PG&E addresses this issue in Chapter 7, Section B.4.

Incorrect Baseline for Risk Analysis

11. Baseline for Risk Selection Should have been 2022 and not 2019

TURN notes that using the correct baseline for risk analysis is necessary to ensure PG&E is not double-counting risk reduction benefits.[87]

TURN states that the S-MAP Settlement Decision requires PG&E to use 2022 as the baseline and not 2019 in order to capture the effects of risk mitigation benefits expected to be achieved prior to the next GRC period. TURN claims that PG&E's scoring of risks for the February 4, 2020 workshop is not consistent with the requirements of the S-MAP Settlement

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85 TURN's February 19, 2020 Letter, p. 7, Item 9.

86 TURN's February 19, 2020 Letter, p. 7, Item 10.

87 TURN's February 19, 2020 Letter, p. 8.

Decision and may have resulted in the incorrect ranking and selection of risks.[88]

PG&E's Response:

PG&E addresses this issue in Chapter 4, Section C.

PG&E's Intentions Regarding Calculation of Risk Reduction for "Controls"

12. Inability to Calculate Control RSEs in RAMP Submission

TURN notes that PG&E stated at the January 13, 2020 workshop that it may not calculate RSEs for controls (mitigations currently in place). TURN views this position as inconsistent with the S-MAP Settlement Decision (Row 26) that requires RSE scores for all RAMP mitigations without distinguishing between new or existing mitigations. PG&E's claimed lack of "counterfactual" data is not a legitimate excuse because Row 31 of the S-MAP Settlement Decision states that "SME judgement should be used if data are not available."[89]

PG&E's Response:

PG&E agrees with SED and TURN that RSE calculations for existing controls can facilitate the evaluation of the overall effectiveness of risk reduction work. However, modeling the controls, which is a precondition to developing RSEs, is not required by D.18-12-014 and PG&E was unable to complete this work for most control programs in time for this RAMP.

TURN describes controls as "mitigations currently in place," and implies that there is no distinction between mitigations and controls in the S-MAP Settlement Decision. However, when it updated the risk lexicon in D.18-12-014, the Commission retained the distinction between mitigations and controls.[90]

Given the accelerated schedule for RAMP, PG&E was not able to model most of its control programs. However, as described at the workshops, PG&E performed pilot evaluations of select control programs in this RAMP. PG&E hopes parties will provide feedback on the pilot methodology used to

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88 TURN's February 19, 2020 Letter, p. 8, Item 11.

89 TURN's February 19, 2020 Letter, p. 8, Item 12.

90 D.18-12-014, 2018 S-MAP Revised Lexicon, pp. 16-17.

evaluate these controls, and PG&E will incorporate that feedback and lessons learned into future risk assessments. We believe that gaining a better understanding of these programs is an essential next step in our risk management evolution.

Insufficient Transparency

TURN states that PG&E has not provided transparency in its calculations and inputs to those calculations as required by Row 29 of the S-MAP Settlement Decision. TURN lists six items that it requires to verify PG&E's risk selection and analysis.[91]

PG&E's Response:

PG&E will provide workpapers supporting its risk models that address each of the six items TURN needs to verify PG&E's risk selection and analysis.[92] Regarding the six items (a-f) requested by TURN, PG&E will provide:

a. The probability distributions on the levels of all attributes in natural units as a consequence of the occurrence of the risk event;
b. The likelihood of occurrence of the risk event;
e. Supporting details showing how the LoRE was calculated; and
f. Supporting details that show how the CoRE was calculated (right side of Bow Tie).

The other two items TURN identified (item c, the likelihood of occurrence of each driver (left side of Bow Tie), and item d, the conditional probability of the occurrence of the risk event, given the occurrence of each driver (left side of Bow Tie)) are not available because PG&E calculates the left side of the Bow Tie directly without going through the two steps TURN calls out. TURN is asking for:

$$\text{LoRE(risk event and driver)} = \text{LoRE(risk event} \mid \text{driver)} \times \text{LoRE(driver)}$$

Because PG&E calculates the left-hand side directly without going through the two steps, PG&E does not have data for items c or d, but does have data for item e (likelihood of occurrence of the event by each driver).

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91 TURN's February 19, 2020 Letter, pp. 8-9, Insufficient Transparency, Item 13.

92 Modeling workpapers will be provided on July 17, 2020.

For example: for the vegetation driver of an ignition event:

a. LoRE(driver) is the probability of having vegetation contact;
b. LoRE(risk event | driver) is the probability of having ignition when there is vegetation contact; and,
c. LoRE(risk event and driver) is the probability of having ignition from vegetation contact.

Other Concerns and Recommendations

TURN identifies three additional concerns and recommendations related to: cyber-related risks; inadequate and/or inaccurate recordkeeping; and weather conditions related to wildfire risk. Weather related issues related to wildfire are addressed in Chapter 10. Cyber-related risk is addressed in Chapter 20, Attachment A, Section B. Recordkeeping is addressed in Chapter 20, Attachment A, Section F.