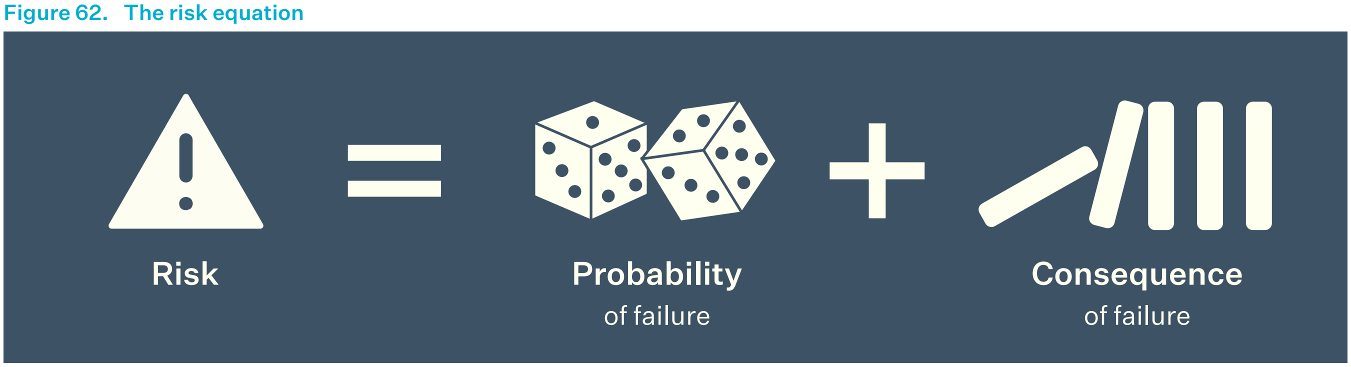
Appendix H. Calculating asset risk

The goal of PGE's Asset Management program is to cost effectively mitigate risk while achieving customer value. PGE's AMP team uses risk-based economic lifecycle models to prioritize long term capital investments. These models calculate the lowest cost of ownership, which is optimal time to replacement of an asset which balances maintenance cost and the risk of owning and operating the existing asset compared to the cost of replacing the asset. Using the outputs of these models to justify proactive asset replacement reduces risk of failure on the system, improves reliability, and improves the customer experience.

The approach the AMP team takes to modeling assets is based on the fundamental concept of risk. Risk is defined as the product of annual probability of failure and consequence cost of failure (**Figure 62**). The annual failure probability is the likelihood an asset will have a repairable or non-repairable failure as a function of its age, condition and model. Consequence cost of failure is the weighted average cost of repairable and non-repairable failure scenarios of the asset. The cost includes reliability impact to customers, load impacted from the failure, along with environmental, safety and direct cost impacts to the company. These concepts are further described below.

Figure 62. The risk equation



H.1 Probability of failure

Modeling annual probability of equipment failure rests on three building blocks:

- The annual failure probability that corresponds to calendar age of the asset via the failure curve
- Identification of any asset degradation via the health index
- Adjustment for any known bad vintages/ manufacturers via a failure multiplier

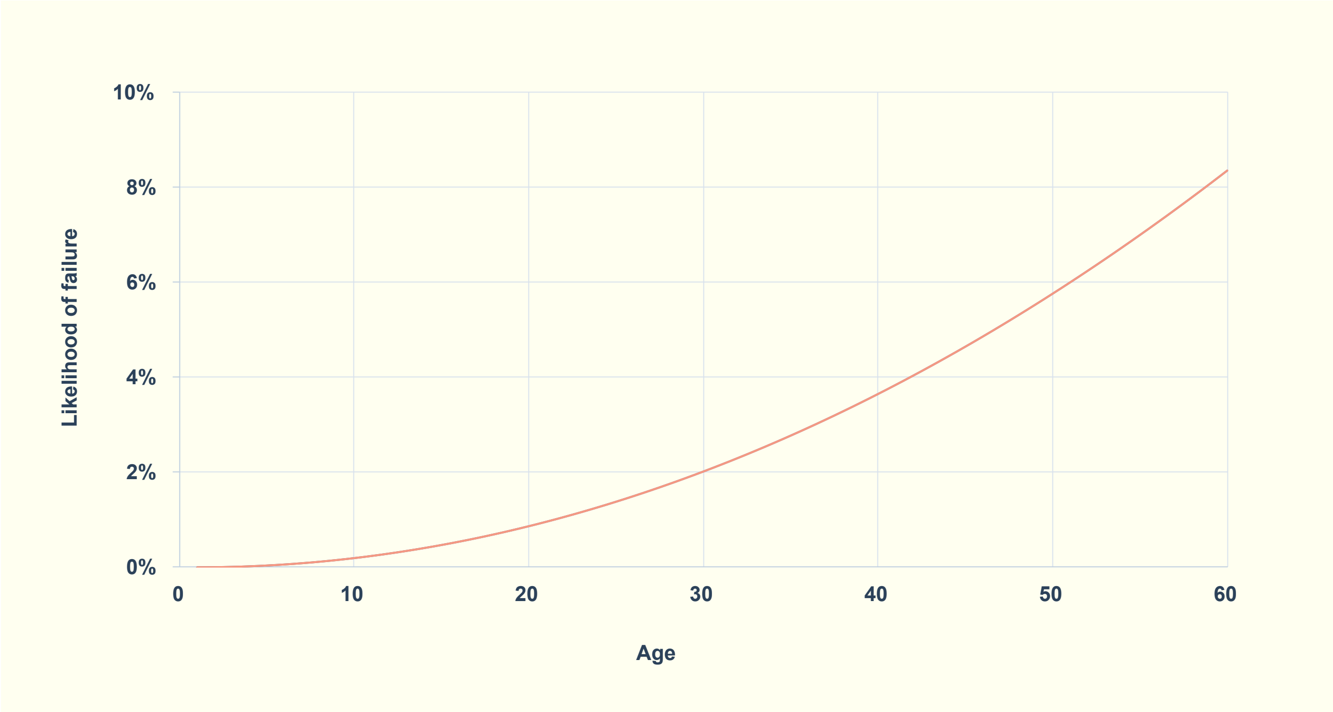
H.2 Failure curves

AMP uses Weibull[88] distributions to statistically model the annual probability of equipment failure. These curves are developed for each asset class family and sub-asset class family, if warranted, to estimate the annual likelihood an asset will fail as a function of its age, assuming it has made it to that age. An example Weibull failure curve is shown in **Figure 63**.

In some cases, an asset family may have several different sub-types of assets with different characteristics and historical failure data. When this happens, different failure curves with different parameters are applied to the different sub-types.

88. Weibull is a continuous probability distribution used to analyze life data, model failure times and assess product reliability.

Figure 63. Example probability of failure (Weibull) curve



H.2.1 HEALTH INDEX

The health index is used to quantify an asset's condition relative to its end of life and calculate the asset's effective age. The health index assesses if the asset is acting older than its calendar age based on poor test or inspection results. If it is acting older than its calendar age, an adjustment to the calendar age occurs to reflect its "true age" via its effective age. This new effective age is then used as the input to the failure curve.

H.2.2 FAILURE MULTIPLIERS

Failure multipliers are identified for "bad actor" types of assets. This may be a particular configuration, manufacturer or production date. PGE subject matter experts identify "bad actors" and assign failure multipliers based on their expertise. The failure multiplier is literally multiplied against the likelihood of failure to elevate the annual failure probability for the "bad actors."

These three components are combined to calculate annual probability of asset failure. **Figure 64** shows an example of how this calculation works.

Figure 64. Failure probability calculation example

What is the annual failure probability based on age?

Develop Weibull failure curves using

- PGE failure data
- Industry information
- Subject matter expertise (SME)

Determine what is the annual failure probability of an asset based on its age

Has any degradation occurred?

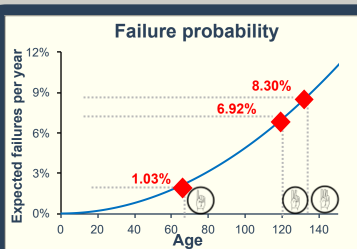
Develop health index (HI) score via SME workshops to

- Identify major mechanisms could lead an asset to degrade or end -of-life
- Identify tests/inspections that tell us how far a degradation process has progressed?
- Identify degradation score for each test/inspection

Are there any known bad vintages, manufacturers or environmental conditions that would make this asset more prone to failure than others in this asset class?

Identify any failure multipliers via SME workshops

- PGE failure data
- SME expertise



Example of annual failure probability summary

Based on age: 46 -year-old transformer = **1.03%**

Including degradation: Solid insulation = **6.92%**

Including failure multiplier: Arcing Tapchanger = **8.30%**

HI = 100 –deterioration | Effective Age = Calendar Age + Deterioration* | "Failure Multiplier" = A number > 1
*An asset's effective age will never be considered younger than it is.

H.3 Consequence of failure

The other half of the risk equation is consequence of failure, which is the quantified impact to PGE and the customer when an asset fails. The customer impact represents about 75%-80% of the overall consequence cost of failure, which is calculated using values of service (VOS) lifted from a Pacific Gas & Electric study approved by the CPUC. In the future, PGE expects to be able to conduct its own customer survey to understand the value of reliability and resiliency for its customer base. The values from PGE's survey would replace Pacific Gas & Electric's VOS values.

To calculate the weighted average consequence cost, subject matter experts identify approximately 4 to 6 different failure scenarios, informed by historical data as available, that range from benign to catastrophic and assign their relative likelihoods.

H.3.1 FAILURE SCENARIOS

Each failure scenario developed for an asset assesses the following and calculates a corresponding cost:

- **Associated damages** — Typically represents costs for adjacent equipment damage
- **Repair cost** — If failure is non-destructive, estimated cost to repair the asset that comes from either a percentage of asset replacement cost, or subject matter expert feedback
- **Additional costs** — Typically represents safety or environmental costs
- **Emergency premium** — Represents the cost to address the failure immediately
- **Outage impact** — Comprised of the following components:
- **Load by impacted customer class** — Asset models use average annual load (kWa) for each customer type (residential, commercial, and industrial) on a feeder or served at a substation
- **Customers impacted** — Total load and customer count impacted
- **Outage type** — Either a sustained outage, which is an outage greater than five minutes, or an extension, which is the extension of an existing outage not caused by the asset in question
- **Outage duration** — How long it takes to restore power to customer, not necessarily how long it may take to repair or replace the failed asset

- **Outage cost** — Quantified by the reliability impact from the event cost plus duration cost for the asset failure by applying customer interruption costs. Outage cost typically represents approximately 75% of the total weighted average consequence cost. These two costs are defined as follows:
    - **Event cost** — For each respective customer class (residential, commercial, industrial), this is the load impacted by failure multiplied by event VOS ($/kW)
    - **Event VOS** — The dollar value customers would be willing to pay per kW to avoid having an outage, irrespective of duration. There are different $/kW assumptions for outage event by customer class (residential, commercial, and industrial).
    - **Duration cost** — For each respective customer class (residential, commercial, industrial), this is the load multiplied by duration value of service (VOS) ($/kWh), multiplied by duration of outage.
    - **Duration VOS** — The dollar value customers would be willing to pay per kW per hour to avoid an outage. There are different $/kW *hour assumptions for outage by customer class (residential, commercial, and industrial).

Using the dollar value and relative likelihood of these failure scenarios, a weighted average is then calculated, which is the dollar-valued consequence associated with asset failure. A graphical representation is shown in **Figure 65**.

Combined with the annual probability of failure, this allows for calculating an annual risk value for each asset for its entire lifecycle. These risk cost streams are then combined with annual maintenance costs, annualized capital costs and discounted using PGE's cost of capital to calculate cost of ownership. This gives present year values which are then used to calculate key metrics for each asset. These metrics are defined in the solution identification section (**Section 5.3.3**).

Figure 65. Transformer failure scenarios and their relative likelihoods