WDRM
System Hardening
Circuit Segment
Methodologies

Table of Contents

1 Model Results Methodologies

The RaDA team probability, consequence, and risk models have been developed to support risk mitigation work prioritization and planning. Frequently, work planning teams need the RaDA model data results to be transformed to match with particular mitigation program's planning requirements. The RaDA team has developed the following model result transform methodologies in support of mitigation program requirements:

- System Hardening Circuit Segments
- Model Results Aggregation

The following sections provide overviews of each of the transform methodologies and their application to RaDA probability, consequence, and risk model results.

1.1 System Hardening Circuit Segments

Circuit Segments are an artificial risk mitigation work planning construct applied to the distribution grid.

A circuit on the distribution grid is the set of electrical grid assets downstream of a substation circuit breaker. However, an electrical circuit is often too large for planning and performing risk mitigation work. Therefore, the System Hardening/Undergrounding wildfire mitigation planning teams have chosen to organize their work by Circuit Segments.

1.1.1 Circuit Segment Definition

A Circuit Segment is the section, or segment, of a circuit and all its connected assets downstream of its closest recloser, or Dynamic Protective Device (DPD). Multiple reclosers on a circuit divide the circuit into various smaller segments such that a fault within any segment will only disrupt power to itself and any downstream segments. An example circuit broken into four Circuit Segments by three DPDs is shown in *Figure 9*.

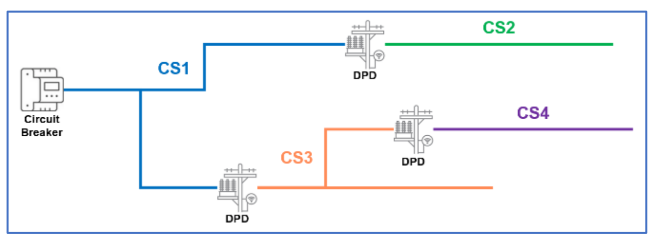

Figure 1 - Circuit Segmentation for Work Planning

There is one significant nuance when defining a work planning Circuit Segment. Some DPDs have switching capabilities that can alter the effective segment configuration during operation. For planning purposes, Circuit Segment configuration is set to match default, or as designed, switch positioning.

1.1.2 Circuit Segment Identification

Circuit Segments are an artificial work planning construct. Each Circuit Segment is identified through logical inspection of the Electrical Distribution GIS (EDGIS) datasets.

1.1.2.1 Circuit Segment Configuration Source Data

The work planning Circuit Segments are determined using grid asset data from three sources:

- Circuit Breaker EDGIS
- DPD EDGIS
- EDGIS Circuit Trace Table

The electrical grid is constantly changing due to maintenance, risk mitigation, and newly installed services. Therefore, it is necessary to use data that is sourced at a specific point in time to minimize configuration mismatches. All three datasets for defining the Circuit Segments are snapshotted by RaDA on the first of each month along with other source datasets necessary for developing risk models. When RaDA begins development on a new set or risk models, all source datasets are synchronized to a common snapshot of data. For WDRM v4, all data is synchronized as of January 1, 2023.

1.1.2.2 Protective Device List

As Circuit Segments are an artificial work planning construct, it is necessary to determine from available GIS datasets which electrical assets serve as segment defining protective devices. For System Hardening, this includes Circuit Breakers and DPDs that meet the following criteria:

- Circuit Breakers
    - Substation full circuit breakers
    - Default position configuration, if applicable
    - Parameter: subtypecd = "Source"
    - Parameter: enabled = "True"
- DPDs
    - Default position configuration
    - Parameter: subtypcd = "Recloser"
    - Parameter: status = "In Service"

For Circuit Breakers and DPDs that include configuration switching functionality, additional logic is applied to include only devices with default, as designed, switch settings.

1.1.2.3 Circuit Segment Protected Asset Identification

For every protective device that serves to identify a Circuit Segment, there is a set of electrical assets that the protective device safeguards. The EDGIS Circuit Trace Table is used to cross-reference each Circuit Segment with its protected assets using the global ID of its protective circuit breaker or DPD.

The Trace Table contains millions of relationships that define the distribution grid configuration. The relationships are inspected to determine the global ID of the closest upstream protective device, and hence the containing Circuit Segment, for each electrical asset on the grid.

1.1.2.4 Circuit Segment Name Assignments

Circuit Segment names are created by combining the circuit name and the protective device operating number for a segment. *Figure 10* provides several examples of Circuit Segment naming for circuit "*El Dorado PH 2101*". The following table illustrates how the circuit name and device operating numbers from *Figure 10* are combined to form unique circuit segment names:

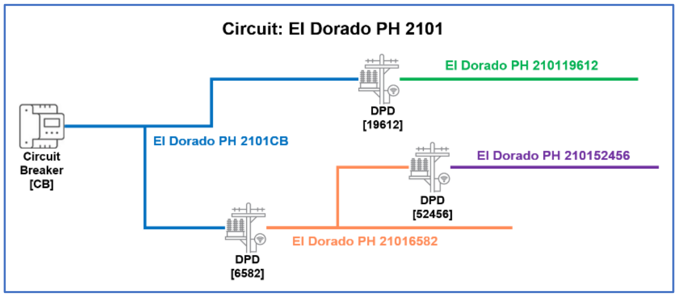

Figure 2 - Circuit Segment Naming

Circuit: El Dorado PH 2101		
Operating Number	**Device Type**	**Circuit Segment Name**
CB	Circuit Breaker	El Dorado PH 2101CB
19612	DPD	El Dorado PH 210119612
6582	DPD	El Dorado PH 21016582
52456	DPD	El Dorado PH 210152456

Table 1 - Example Circuit Segment Names

It is important to remember that Circuit Segment names reflect a fixed point in time. The grid is continuously evolving for reasons such as adding new services, inserting new protective devices for PSPS or EPSS, undergrounding portions of circuits, and replacing or removing circuit sections. Each time the grid configuration changes, one or more Circuit Segments may see a change in name, length, or protected assets. This is the primary reason why the RaDA risk modelling work is always anchored to a set of EDGIS datasets captured at a common date to ensure that mapping of risk results is consistent.

1.1.2.5 Circuit Segment Geometries

Multiple user requirements for the RaDA risk model results are satisfied through analysis of the Circuit Segment geometries. Circuit Segment shape geometries are determined via the cross-referenced protected primary and secondary conductor records from the EDGIS Circuit Trace Table. The geometry of each Circuit Segment protected conductor section is merged to create the total geometry.

The Circuit Segment geometries are required to satisfy two significant user requirements:

- Display risk model results on maps in Foundry as well as other systems such as ArcGIS.
- Determine Circuit Segment lengths in defined areas such as:
  - HFRA
  - HFTD Tier 2
  - HH Zone 1
  - Region
  - HFTD
  - HFTD Tier 3
  - County

Note that location of non-conductor assets, which have point locations rather than geometries, are not merged into the Circuit Segment shape geometry.

1.1.3 Circuit Segment Use for Risk Models

As required by the System Hardening and Undergrounding risk mitigation work planning teams, model results from the Distributions Event Probability Models, the Wildfire Consequence Model, and the Wildfire Distribution Risk Model are aggregated to Circuit Segments. Work planners consider the relative aggregated values for probability of ignition, wildfire consequence, and wildfire risk to prioritize the timing, type, and amount of risk mitigation work that will be performed on high risk Circuit Segments, especially in high fire risk areas.

Aggregation and compositing of risk model results to Circuit Segments are described in Sections *1.2* and *1.3* of this document.

1.1.4 Circuit Segment Vintage Warning

The GIS datasets used to create a set of distribution Circuit Segments are constantly changing to reflect the current physical state of the grid. While it is possible to continuously update the Circuit Segments as the underlying GIS datasets are updated, this is not useful from a risk modeling perspective. Therefore, any risk model produced by the RaDA team will have a GIS vintage date associated with it. The GIS vintage date for a risk model is recorded as part of its provenance metadata. Users are advised to check and consider the Circuit Segment vintage date when trying to compare or merge risk model results with Circuit Segment based datasets produced outside of the RaDA team.

1.2 Model Results Aggregation

1.2.1 Introduction

RaDA produces both asset and spatial models. Asset models produce results that estimate event probabilities or risk for individual assets at point locations. Spatial, or grid pixel, models, product results that estimate event probabilities or risk within 100m by 100m square pixels that form a grid over the distribution and transmission service territories.

Many end users need to understand model results in a larger context than the direct model outputs. The most used context is Circuit Segment based values. Other contexts that have been requested include county and regional based values. Providing these values requires that the asset and spatial model results be aggregated to the desired context.

1.2.2 Circuit Segment Line Geometry Aggregation

A common user requirement is aggregating model results to a line geometry. While there are several permutations of line geometry possible for the electric grid, the only aggregation currently supported by the RaDA team is the System Hardening Circuit Segment. The aggregated model result for a Circuit Segment is the sum of two components, grid pixel model result values aggregation and asset model result values aggregation.

1.2.2.1 Grid Pixel Aggregation

Many of the RaDA risk models produce results for 100m by 100m grid pixels that overlay our service territory. Pixel model results are aggregated to line geometries like Circuit Segments by summing the model result value for each grid pixel that intersects spatially with the Circuit Segment geometry. *Figure 11* presents a single Circuit Segment that intersects with 14 grid pixels. The aggregated model result value for the Circuit Segment is the simple sum of all intersecting pixel values.

CS Aggregated Pixel Value = A5 + A6 + B1 + … + I7 + J8

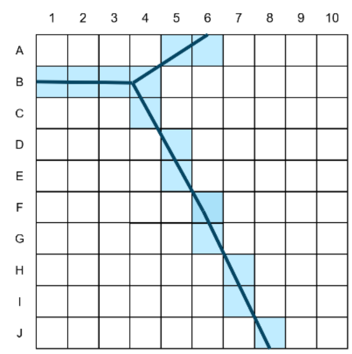

Figure 3 - Single Circuit Segment Pixel Aggregation

Aggregating model results is a bit more complicated when multiple Circuit Segments intersect with one or more shared pixels as shown in *Figure 12*. If the same model result value is summed to both Circuit Segments, then you end up with more summed total Circuit Segment result values then is modeled for the entire grid. In other words, the sum of all Circuit Segment results would be greater than the sum of all pixel results.

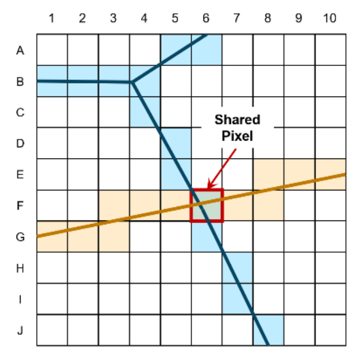

Figure 4 - Multi-Circuit Segment Pixel Aggregation

The model results aggregation is modified for shared pixels by dividing the model result for each shared pixel by the number of Circuit Segments that intersect it.

Blue CS Aggregated Pixel Value = A5 + … + F6/2 + … + J8

Orange CS Aggregated Pixel Value = G1 + … + F6/2 + … + E10

1.2.2.2 Asset Value Aggregation

Several event probability models produced by RaDA produce results by unique assets. Asset model results are aggregated to line geometries like Circuit Segments through parent-child relationships between assets kept in various system of record databases. Most assets relationships can be established using the EDGIS Circuit Trace Table. Unfortunately, support structure assets are not included in the Circuit Trace Table and their relationship to other assets must be inferred through multiple data sources.

1.2.2.2.1 EDGIS Circuit Trace Table Assets Assignment to Circuit Segments

The EDGIS Circuit Trace Table, which is used to identify and name Circuit Segments, also serves to relationally identify most electrical assets that are associated with a Circuit Segment. This includes:

- Capacitor Banks
- Dynamic Protection Devices (DPDs)
- Fuses
- Primary Conductors
- Switches
- Transformers
- Voltage Regulators

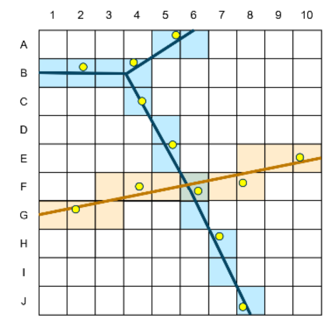

Figure 5 - Circuit Segment Assigned Assets

Unfortunately, Support Structures, which are not energized assets, are not included in the trace table.

Figure 13 presents two Circuit Segments showing both their assigned pixels and assets.

1.2.2.2.2 Support Structure Assignment to Circuit Segments

Support Structures, or poles, require specialized logic to determine their owning Circuit Segment(s). As noted in the prior section, Support Structures are not recorded in the EDGIS Circuit Trace Table as they are not energized assets. Currently, there is no comprehensive single data source that definitively relates Support Structures with Circuit Segments.

Support Structures to Circuit Segment(s) relationships are established through a cascaded search of two datasets in the following order of preference:

1. RaDA's Manual Assignment Dataset
2. Asset Knowledge Management (AKM) Pole to Conductor Dataset

1.2.2.2.2.1 RaDA Manual Assignments

There is a known issue with the AKM Pole to Conductor dataset for assets near electrical stitch points and circuit breakers where there are sometimes too many conductors, and by association circuit segments, assigned to a single support structure. For cases where there are four or more circuit segments linked to a support structure, the RaDA team manually uses the EDGIS Web Viewer to review conductor connections and create a custom support structure to circuit segment lookup dataset.

Figure 14 provides an example of the potential need for a manual assignment. The magenta dots represent support structures where there is the potential for as many as four Circuit Segment that could be assigned to each of the poles. The RaDA Manual Assignment Dataset would be used to determine the Circuit Segment and Support Structure relationships.

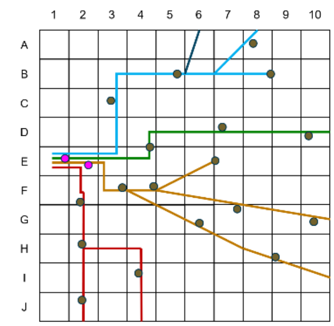

Figure 6 - Circuit Segment Support Structure Assignments

1.2.2.2.2.2 Asset Knowledge Management (AKM) Pole to Conductor Dataset

The AKM team maintains a dataset that is the most reliable source for understanding relationships link between distribution support structures and conductors. The AKM team actively works to maintain and enhance the dataset. The AKM dataset is used for establishing nearly all of the conductor to support structure relationships with the few exceptions originating from the RaDA Manual Assignments dataset described in the prior section. The AKM dataset is snapshotted monthly to support synchronization of model data for development.

1.2.2.2.3 Asset Model Result Aggregation to Support Structures

The following assets have one-to-one relationships with Circuit Segments:

- Capacitor Banks
- Dynamic Protection Devices (DPDs)
- Fuses
- Primary Conductors
- Switches
- Transformers
- Voltage Regulators

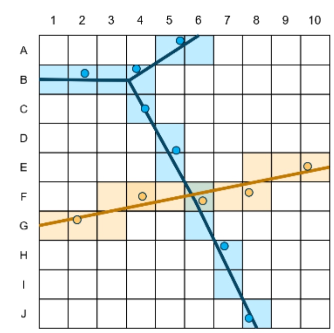

Figure 7 - Direct Asset Risk Aggregation to Circuit Segment

The risk results for these assets list above can be directly attributed to a Circuit Segment. *Figure 15* shows two circuit segments and their directly associated assets for aggregation.

1.2.2.2.4 Support Structure Result Aggregation to Circuit Segments

Support Structure and Primary Conductor risk results are attributed to specific poles. Many poles are associated with multiple Circuit Segment. Pole-based risk results are therefore apportioned equally to associated Circuit Segment depending on the number of connected Circuit Segments. *Figure 16* presents three Circuit Segments with a few shared poles. Their risk results would be assigned and summed as follows:

- Blue CS = 1/3 Red + 1/2 Magenta + 3 Blue
- Green CS = 1/3 Red + 1/2 Magenta + 2 Green
- Brown CS = 1/3 Red + 3 Brown

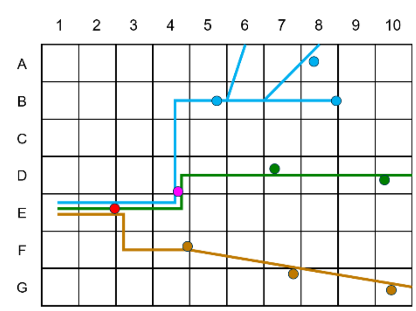

Figure 8 - Pole-based Asset Risk Aggregation to Circuit Segment

1.3 Model Results Compositing

The ultimate purpose for the RaDA risk models is to inform the prioritization of risk mitigation programs. The event probability model risk results can be flexibly composited to provide probability values, risk values, and priority rankings for specific mitigation programs. Using composited results, programs can prioritize mitigation of the highest total risks while using the contributing event probability models to understand the best mediation approach to handle the specific components of risk.

Risk can be composited for any combination of event probability models. Mitigation planners and Subject Matter Experts can focus on the drivers of risk for which they are responsible with confidence that their composited view is relevant to their work planning needs.

1.3.1 Compositing Methodology

An event probability model produces, by asset or pixel, a probability of ignition. Combining a probability of ignition with its consequence produces the wildfire risk. Probability of ignition and risk results can be composited to create total probability of ignition and total risk values. Compositing methodology has evolved as the distribution event probability models have matured and improved.

In producing the WDRM v3, all event probability model results were composited on a pixel basis and equipment asset results were spatially assigned to circuit segments. Unfortunately, a significant number of pixels contain multiple circuit segments. As risk results were attributed to a pixel, v3 compositing lacked a methodology for attributing asset risk at a pixel level proportionally to a specific circuit segment. Therefore, pixel risk would be divided equally between all circuit segments that crossed through a pixel.

For WDRM v4, most of the equipment asset models produce results on an individual asset basis and each asset's relationship with a containing circuit segment is traced through various GIS and SAP data sets. Therefore, equipment asset risk can be attributed directly to a circuit segment, eliminating the shared risk approach necessary for pixel-based results using for v3.

The compositing methodology used by the RaDA team in support of the WDRM is currently a three step process:

1. Composite pixel model results.
2. Composite equipment asset model results.
3. Aggregation of pixel and asset composite values

1.3.1.1 Compositing Pixel Model Results

Models that produce pixel results are typically spatially oriented in the context of the risk than threatens the electrical grid network. *Figure 17* depicts a single pixel with multiple potential spatial threats. Individual event probability models for vegetation, animals, and third party events have produced high, medium, and low risk results, respectively for this particular pixel. Mitigation programs are typically interested in comparing the total risk for the circuit segment that passes through this pixel relative to other circuit segments where work might be performed.

Pixel model results are very straightforward to composite, this risk values from each of the contributing pixel models are simply summed to determine the composite risk for a pixel:

$$Composite\ Risk_{pixel} = \sum_{1}^{n} Pixel\ Model\ Risk$$

Figure 18 presents the composited risk value for the example pixel. For this example, a high vegetation risk result and a significant animal risk combine to produce a relatively high overall pixel model risk result for any circuit segment that passes through the pixel.

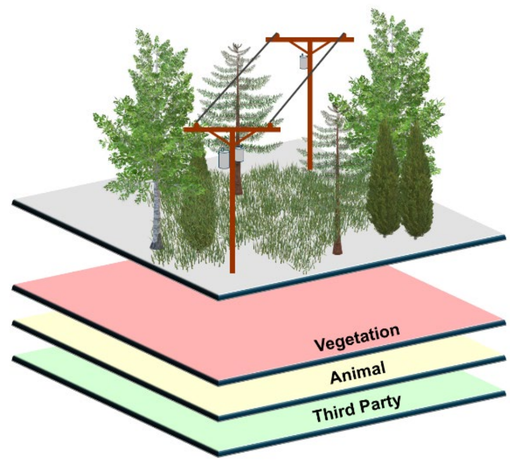

Figure 9 - Pixel Model Layers

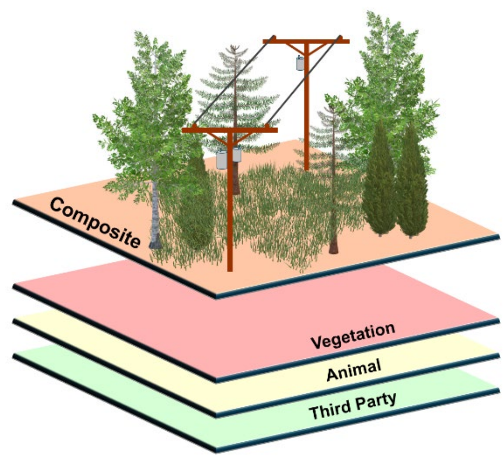

Figure 10 - Composited Pixel Result

1.3.1.2 Compositing Equipment Asset Model Results

Equipment asset models produce risk results that are specific to individual assets. *Figure 19* depicts a very simple example of a circuit segment. Even simplified, there are multiple modeled assets represented, including:

- Two support structures
- Two primary conductor spans
- Three attached transformers

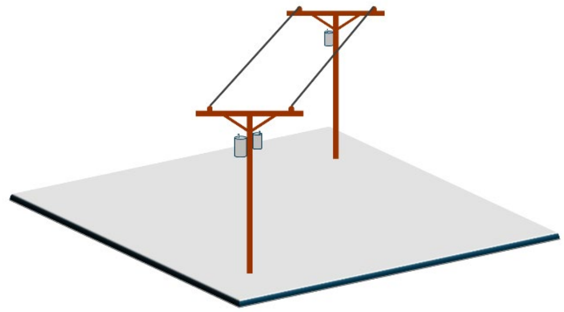

Figure 11 - Simplified Equipment Asset Example

Risk results are generated by the appropriate equipment asset model for each piece of equipment. *Figure 20* displays visually the risk results for each of the individual assets that make up the simple circuit segment. Note that the two support structures, the two conductor spans, and three transformers each have different levels of risk assigned to them.

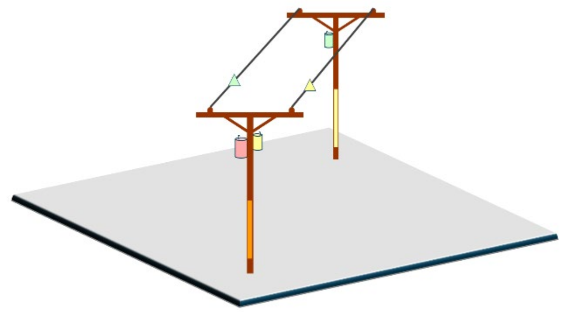

Figure 12 - Individual Equipment Asset Risk Results

The overwhelming majority of equipment assets are pole based. Therefore, equipment assets are composited to the support structure that holds the asset. Conductor spans are a special case in that they are supported by two poles, and hence, their risk must be distributed equally to their support structures.

Figure 21 depicts the compositing of equipment asset risk to the containing support structures. The composite risk indicator at the base of each support structure combines the risk for the pole, the equipment attached to the pole, and half of the conductor risk. Note that any pole with a significant number of attached equipment assets is likely to have a relatively high composite risk simply due to the number of assets.

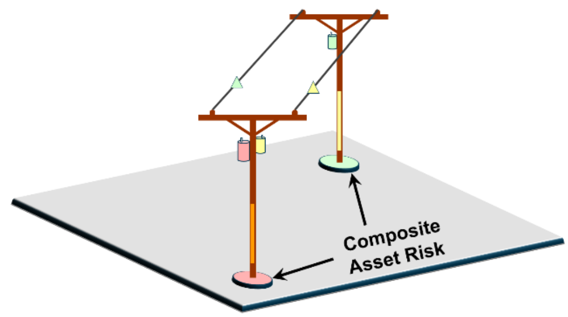

Figure 13 - Composited Asset Risk Example

1.3.1.3 Aggregation of Pixel and Asset Composite Results

Composite pixel and equipment asset results are typically aggregated to the context of circuit segment risk values for mitigation work planning.

Figure 22 depicts a single circuit segment that spans multiple grid pixel areas and has several equipment assets. The aggregated risk value for this segment is the combined sum of three composite pixel risk values and four composite asset risk values.

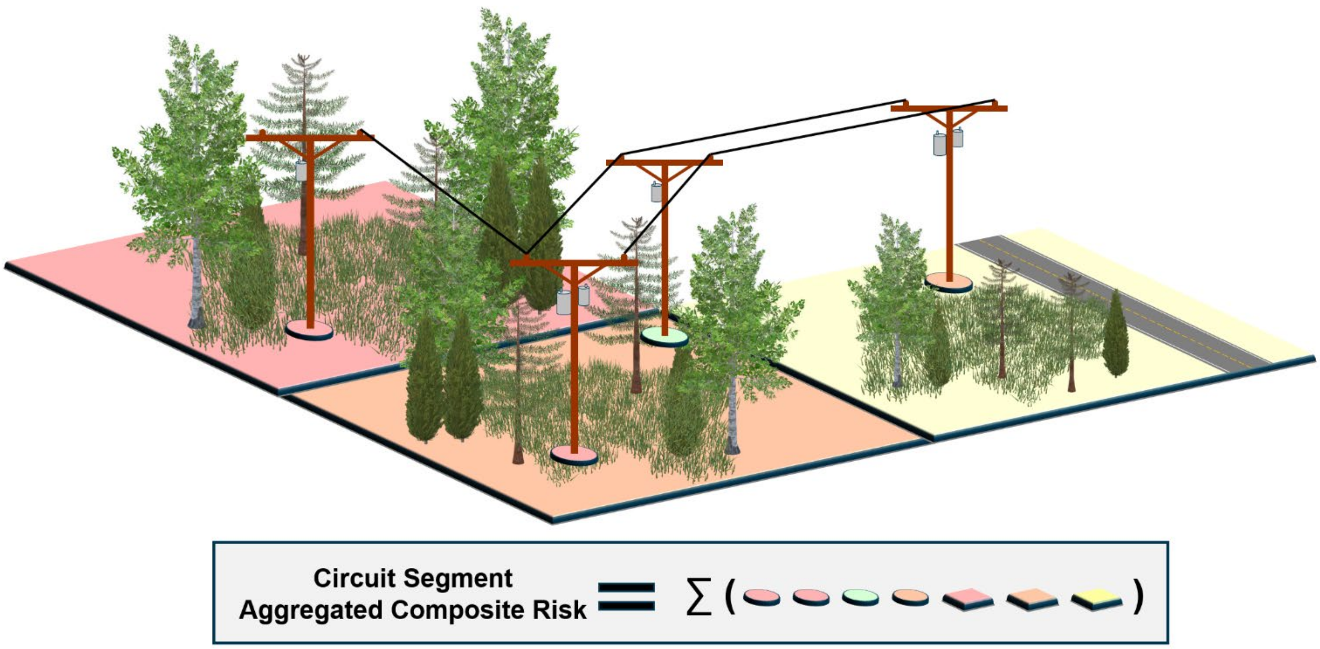

Figure 14 - Single Circuit Segment Aggregated Composite Example

The electrical grid network, however, is more complicated than the example present above. Sometimes, a support structure supports conductors for more than one circuit segment. Another common configuration issue is when multiple circuit segments pass through the same grid pixel. In these cases, some the aggregation must distribute the shared risk. *Figure 23* presents a configuration where two of the grid pixels are spanned by two distinct circuit segments. In this case, while asset risk can be directly attributed to its containing circuit segment, the grid pixel risk must be equally shared by the two segments.

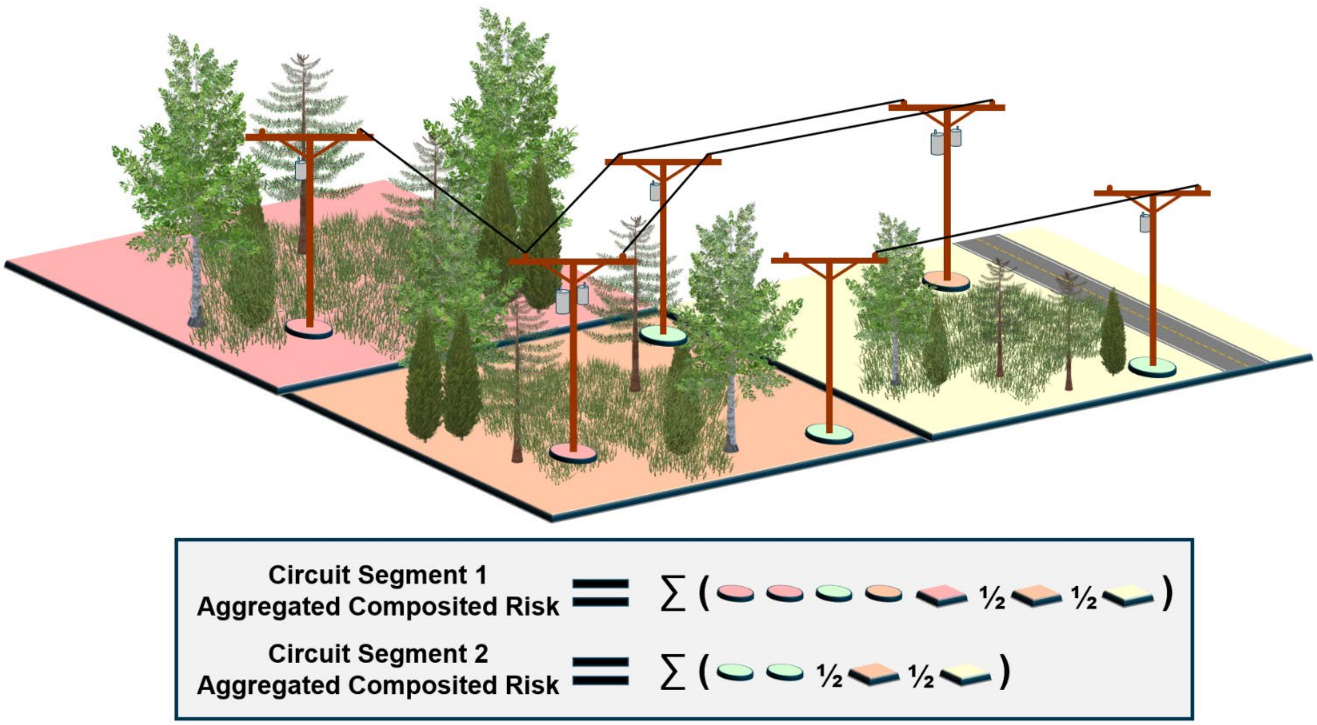

Figure 15 - Multiple Circuit Segment Aggregated Composite Example

1.3.1.4 WDRM v3 and v4 Circuit Segment Composite Aggregation Comparison

The aggregation of composited risk is a major difference between WDRM v3 and v4, and the updated aggregation results in more accurate relative circuit segment risk scores for v4. The single pixel circuit segment configuration provided in *Figure 24* will be used to illustrate the difference between v3 and v4 circuit segment risk values. Note that a set of example risk values have been associated with the icon colors in the figure.

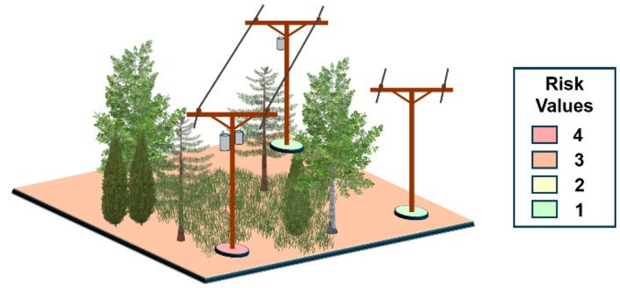

Figure 16 - v3/v4 Circuit Segment Risks Example

For v3, all event probability model risk results were recorded as pixel values. For the sake of brevity, the asset composite results presented in *Figure 24* will be assumed to be pixel level results. For v3, a composited pixel risk value would be calculated and distributed equally to the two circuit segments that cross the pixel as shown in *Figure 25*. In the example, each circuit segment would be assigned a risk value of 4.5 and the two circuits would be considered to be of equal priority for mitigation work.

Figure 17 - WDRM v3 Circuit Segment Pixel Risk Assignment

In contrast, for v4 the equipment asset risks are directly assigned to their containing circuit segments and only pixel model risk is shared equally between the two circuit segments. *Figure 26* illustrates that the direct assignment of asset risk results in different circuit segment risk values, and hence, very different priorities for receiving potential mitigation work. This result makes sense, as one segment has an asset with considerably greater wildfire risk than the other.

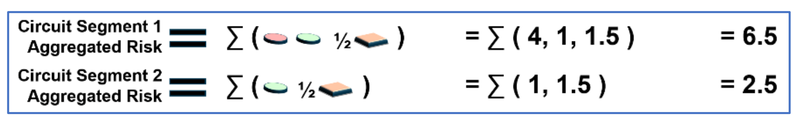

Figure 18 - WDRM v4 Circuit Segment Asset & Pixel Risk Assignment