IBEC Consulting Report

by

The Data Fiends

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SYNOPSIS

The Itty-Bitty Electric Company (IBEC) provides electric service to a large territory across Southern California. Due to frequent and long-lasting outages across its circuits, they have been facing high numbers of Customer Minutes of Interruption (CMI). This report presents a data-driven strategy to identify high-risk circuits and recommend upgrade priorities that maximize impact on reliability. By conducting statistical analysis and focusing on customer-centric prioritization, our proposal aims to help IBEC determine the best areas to upgrade. Our recommendations aim to reduce unplanned outages, shorten courage duration, and enhance overall customer satisfaction, supporting IBEC's long-term infrastructure growth strategy.

BACKGROUND OBSERVATIONS

1. SWOT Analysis

SWOT (Strength, Weakness, Opportunity, Threat) analysis is a valuable technique to identify IBEC's initial strengths and weaknesses to help derive a strategic plan for future opportunities and be aware of any potential threats in the market. Below is a SWOT analysis for IBEC:

Strengths

- Extensive Service Coverage: IBEC operates across a broad region in Southern California, providing access to a large customer base, which strengthens its market presence.
- Strong Customer Relationships: Since it operates across a large region, it has built customer trust and loyalty which will help when introducing new programs and technologies.

Weaknesses

- Limited Technological Expertise: IBEC currently lacks a technology team with expertise in the latest analytics technologies like machine learning and artificial intelligence. This limits the company's ability to implement advanced analytical solutions like predictive analysis.
- Outdated Infrastructure: Some infrastructures in certain regions may be outdated, making it more prone to interruptions and could lead to higher maintenance costs.

Opportunities

- Technology Adoption: By developing internal resources used by the technology team, IBEC has the opportunity to enhance its service reliability leading to more efficient maintenance, outage prevention, and reduced customer interruption times.
- Data-Driven Decision Making: Given the existing data, new technologies will support smarter investment decisions, especially in infrastructure upgrades.

Threats

- Environmental Risks: The Southern California region is vulnerable to natural disasters like wildfires and earthquakes, posing as significant threats that are outside of IBEC's control.
- Budget Constraints: Due to limited financial flexibility, IBEC must prioritize their investments carefully and focus on areas that yield the greatest return whilst minimizing costs.

2. Key Observations

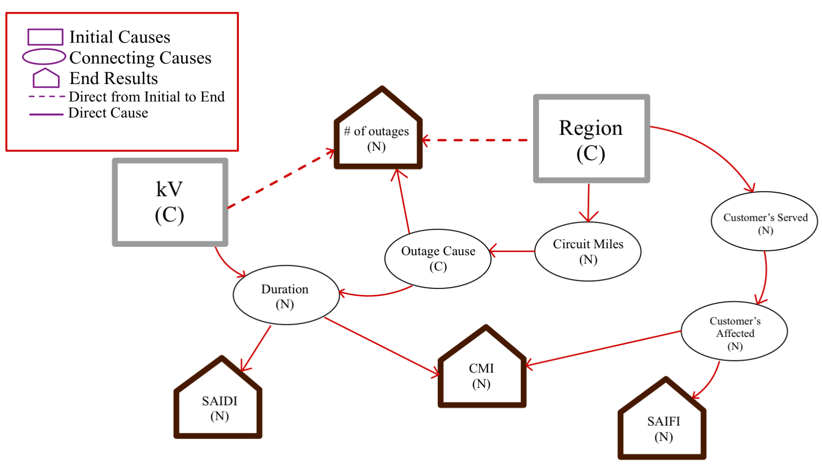
IBEC seeks to improve reliability by minimizing CMI through smarter system upgrades in the Southern California Region. CMI is influenced by two factors, the number of customers interrupted and the duration of the interruption. This metric is used to measure the overall impact of outages on customers to evaluate the reliability of the power distribution. Some outages lasted over 1000 minutes, highlighting aging infrastructure and/or slow restoration protocols. Moreover, a small number of outage causes contribute to the majority of customer minutes lost.

- **Data Concerns & Assumptions:**
  1. Some outage durations had formatting issues (e.g., commas in numbers).
  2. Assuming circuit-level metadata (e.g., age, terrain, historical investments) is available internally or can be augmented.
  3. The dataset does not include weather correlation or geolocation, which are valuable for predictive modeling.
  4. The data set had limited data and had small samples making it more difficult to maximize accuracy and analyze trends. Some circuits claim to only have a handful of outages, which is unhelpful for predictive analysis.

- **Risks and Business Impact:**

Potential Risk	Business Impact
Inaccurate or missing data on circuits/outages	Misallocated upgrade budgets
Data bias toward only reported outages	Underestimation of critical weak points
Lack of integration with external risk signals (ex: weather, vegetation)	Missed predictive upgrade opportunities

Visual Mapping



In order to understand the relationship between the given data, the map below would visually explain how each data point would affect another. Using outside sources, we were able to simplify the cause and effect of each column of the data set.

Fig. 1. Visual Map

The columns are labelled by the kind of data point they are, (C) for Categorical and (N) for numerical. A legend is given in the red box.

Starting with the factors kV and Region, these are fixed constants, something that we would need to purposefully change. For example, if a circuit like Orange is fixed at 4 kV, it is quite difficult to physically change the circuit. Additionally Orange is in the coastal region, which is a geographical location that is also fixed.

Moving on to the connecting causes, these are factors that are affected by one of the initial causes, which in turn affect each other. For example, the region a circuit is placed in affects the amount of customers served, since customers typically have preferences in the area they choose to live in. The amount of customers served directly causes the amount of customers affected.

Additionally, the region also affects the circuit miles, since the type of region can affect the ability of the company to place such circuits. For example, it is much harder and expensive to place circuits in the mountains compared to the coastal areas. The amount of circuit miles affects the outage cause since this determines how much overhead miles are placed. Overhead miles are more likely to be affected by the given causes like animals, weather, and vegetation. Underground miles can still be affected, but are less likely to. Lastly, the cause of the outage directly affects the duration of the outage. In the analysis below, we break down how much each cause can affect the duration. Based on outside sources, some causes can make the outages last longer than others.

The end results are factors that do not necessarily affect something else. For example, the number of outages affects the company directly, but not any other factors in the data set. The SAIDI and SAIFI are calculated using data points in the data set, but will not affect anything else. Lastly, the CMI is not given in the data set, but is something that we want as a result.

<u>THE DATA</u>

Two datasets were given to analyze. Here is a breakdown of how we cleaned the dataset and what each column told us.

1. Circuit Outage Dataset

100 circuit outage observations. We were given the Circuit Name, Outage Date, Outage Duration, Outage Cause, and the Number of Customers Affected.

Columns:

- **(Circuit Number) Circuit Name [CATEGORICAL]**: (1) Orange, (2) Alabama, (3) Green, (4) Oregon, (5) Yellow, (6) Washington, (7) Lincoln, (8) Johnson, (9) Magenta, (10) Adams, (11) Roosevelt, (12) Jefferson, (13) Gorilla, (14) Blue Jay, (15) Thunder, (16) Lightning, (17) Hoover, (18) Monterey, (19) Logan, (20) Grand, and (21) Dinan.

- **Outage Date [CATEGORICAL]**: formatted in day/month/year.
- **Outage Cause [CATEGORICAL]:**
    - Weather: An interruption on the supply of electricity caused by natural weather phenomena like severe storms, extreme heat, wildfires, and freezing weather. These can damage the power lines and infrastructure.
    - Vegetation: An interruption of power supply that is caused by the overgrowing of plants, trees, shrubs, and other vegetation on or near the power lines. This physical contact with the lines can cause short circuits and damage.
    - UG Equipment Failure: An interruption that is caused by malfunction or damage of underground electrical equipment like cables, transformers, and other components.
    - Third Party: This refers to third party providers that are attached to the company, like suppliers, vendors, like cloud computing providers, internet service providers.
    - Operation: Errors in voltage control, thermal limits, contingency plans, hardware, software, human error, as well as other things like gas leaks.
    - OH Equipment Failure: An interruption that is caused by malfunction or damage of overhead (above ground) electrical equipment like cables, transformers, and other components.
    - Animal: Most common in public power utilities, where animals like squirrels, raccoons, snakes, and affect the overhead and exposed circuit lines.
    - Other: An interruption that is not caused by any other factor provided in this list.
- **Customers Affected [NUMERICAL]**: Customers affected per circuit outage.
- **Outage Duration [NUMERICAL]**: How long the circuit outage was in minutes.

2. LookUp Dataset

Descriptions of each Circuit Name (21 rows). Gives the KV, Region, Customer Counts, Circuit Miles, Percentages of Overhead and Underground circuits, the SAIDI, and SAIFI for each circuit. The dataset is from the year 2023, and we are assuming all the factors of the circuit remain the same for 2024 except for the SAIFI and SAIDI.

Columns:

- **(Circuit Number) Circuit Name [CATEGORICAL]:** (1) Orange, (2) Alabama, (3) Green, (4) Oregon, (5) Yellow, (6) Washington, (7) Lincoln, (8) Johnson, (9) Magenta, (10) Adams, (11) Roosevelt, (12) Jefferson, (13) Gorilla, (14) Blue Jay, (15) Thunder, (16) Lightning, (17) Hoover, (18) Monterey, (19) Logan, (20) Grand, and (21) Dinan.

- **KV [CATEGORICAL]:** The amount of electricity that can be pushed through the circuit. There are three KV values in this dataset:
    - **4 KV**: this amount of KV is typically used for low voltage distribution lines, often in areas with lower power demands, like residential neighborhoods
    - **12 KV**: this amount of KV is a medium voltage level that provides a balance between voltage stability and has the ability to carry sufficient power to neighborhoods and commercial areas
    - **16 KV**: this amount of KV is used for high capacity distribution lines, main serving industrial areas or commercial buildings.
- **Region [CATEGORICAL]:** The general terrain and area of each circuit
    - **Coastal:** Areas right next to the ocean. Coastal weather is prevalent, and these regions could handle humidity and storms.
        - <u>Circuits in this Region</u>: Dinan, Green, Jefferson, Orange, Roosevelt
        - In Southern California, the counties reflecting this region are Los Angeles, Orange, San Diego, Ventura, and Santa Barbara.
    - **Mountain**: Areas characterized by high terrains with steep slopes. In higher elevations, it is susceptible to a range of weather conditions: snow, wind, etc. In addition, the mountains are the home of a diverse group of animals and plants.
        - <u>Circuits in this Region</u>: Grand, Johnson, Lightning, Lincoln, Magenta, Thunder
        - In Southern California, the county reflecting this region is San Bernardino
    - **Desert:** Areas that receive no more than 25 centimeters of precipitation. Characterized by its extreme heat and dry weather.
        - <u>Circuits in this Region</u>: Adams, Blue Jay, Gorilla, Monterey, Oregon
        - In Southern California, the counties reflecting this region are Riverside and Imperial
    - **North:** Referring to the northern parts of the service areas. This region experiences more seasonal weather changes – temperature fluctuations throughout the year, and harsher weather throughout the seasons.
        - <u>Circuits in this Region:</u> Alabama, Hoover, Logan, Washington, Yellow
        - In Southern California, the counties reflecting this region are Bakersfield and San Luis Obispo.

- **Customer Count [NUMERICAL]**: The total number of customers the circuit serves.
- **Circuit Miles [NUMERICAL]**: The total length, in miles, of the circuit. This tells us how far the circuit covers.
- **Overhead [NUMERICAL]**: The percentage of overhead (above-ground) circuits.
- **Underground [NUMERICAL]**: The percentage of underground circuits.
- **SAIDI 2023 [NUMERICAL]**: Stands for System Average Interruption Duration Index. Measures the total duration of ALL outages experienced by the average customer affected during the year 2023.
    - An example to interpret the values: For the Orange circuit, each customer experienced 0.1833 hours of outage during a period for the entirety of 2023.
- **SAIFI 2023 [NUMERICAL]**: Stands for System Average Interruption Frequency Index. Measures the average number of times a customer experiences an outage during the year 2023.
    - An example to interpret the values: For the Orange circuit, each customer experienced 0.0032 outages during the period for the entirety of 2023

3. Added Columns

We mainly added more columns to the Look Up dataset inorder to get a better view of both 2023 and 2024 data.

- **Average Outage Duration per Customer in 2023 [NUMERICAL]**: Calculated by multiplying the SAIDI 2023 column by 60. Since SAIDI told us the fraction of hours a customer experienced, multiplying the SAIDI by 60 will tell us the number of minutes.
- **Number of Outages [NUMERICAL]**: Tells us the number of outages each circuit had in 2024. Information taken from the Circuit Outage dataset.
- **Underground Miles [NUMERICAL]**: Taken from multiplying the Underground and Circuit Miles columns.
- **Overhead Miles [NUMERICAL]**: Taken from multiplying the Overhead and Circuit Miles columns.
- **Average Customers Affect in 2024 [NUMERICAL]**: Information from the Circuit Outage data set. Tells us the average customers affected per circuit in 2024
- **Total Outage Duration 2024 [NUMERICAL]**: Information from the Circuit Outage data set. Tells us the total outage duration a circuit caused in 2024

- **SAIFI 2024 [NUMERICAL]**: Calculated by dividing the Number of Outages in 2024 by the Customer Count. Tells us the average number of times a customer experiences an outage during the year 2024

- **SAIDI 2024 [NUMERICAL]**: Calculated by dividing the Total Outage Duration of 2024 by the Customer Count. Tells us the total duration of ALL outages experienced by the average customer affected during the year 2024

- **Average Outage Duration per Customer in 2024 [NUMERICAL]**: Calculated the same way as Average Outage Duration per Customer in 2023.

- KV-Miles [NUMERICAL]: Calculated by multiplying the KV and Circuit Miles columns together. Informs us of three things: 1) the circuit is long distance, 2) the circuit is more powerful with a higher voltage (KV), 3) the circuit is both.

SCOPE AND OBJECTIVE

Our primary goal is to help IBEC strategically allocate its system maintenance and upgrade budget by identifying the circuits that contribute most significantly to system unreliability–measured through high Customer Minutes of Interruption (CMI)–and the conditions that make circuits more resilient. We want to focus on the specific regions, types of upgrades, and take customer satisfaction into account. By analyzing both historical outage data and key circuit characteristics, we aim to uncover patterns that reveal:

- Which circuits are most problematic and should be prioritized for upgrades.
- What circuit conditions are predictive of fewer and shorter outages.
- How IBEC can optimize customer satisfaction by reducing outage duration and frequency in high-impact regions.

To identify the most problematic circuit, we evaluate based on the number of customers affected first of all. We are committed to delivering the best services to our customers; hence, we prioritize customer impact above all. To find the number of customers affected first, we evaluate the circuit per region. Once we know which circuits are the most affected in terms of customers, we evaluate the circuits by the number of circuit outages. Some circuits cover a larger group of people but will only have one circuit outage, so it’s important to figure out which circuit has the most amount of outages as well.

We will leverage advanced analytics and machine learning techniques to assess where unplanned outages most frequently occur, what their root causes are, and what shared traits high-performing circuits exhibit. These insights will inform data-driven decisions on infrastructure investments—such as undergrounding lines or replacing vulnerable equipment—while ensuring regulatory justification in future rate cases.

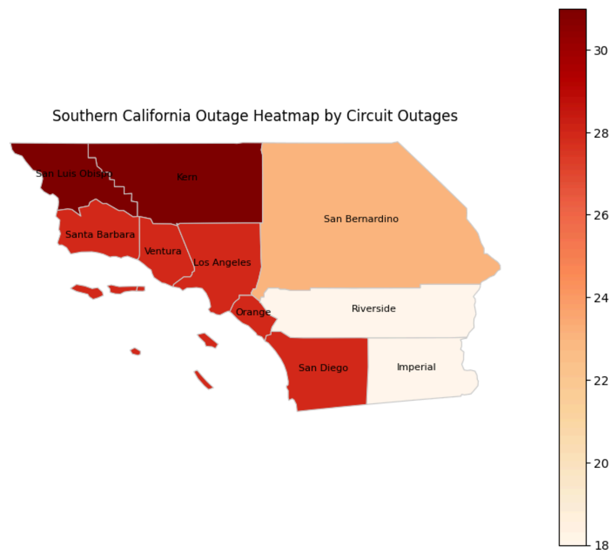
This project will also consider regional disparities, recognizing that certain geographic areas may require tailored solutions due to environmental, demographic, or infrastructure differences. Ultimately, this approach aims to enhance grid reliability, improve customer satisfaction, and deliver a clear return on investment for every dollar spent on upgrades.

DATA ANALYSIS AND INSIGHTS

1. Finding the Most Problematic Circuit

Since we want to focus on our customers, we wanted to see a heat map of Southern California that shows where the most circuit outages are happening and where most customers are being affected. We categorized each region into a county in California:

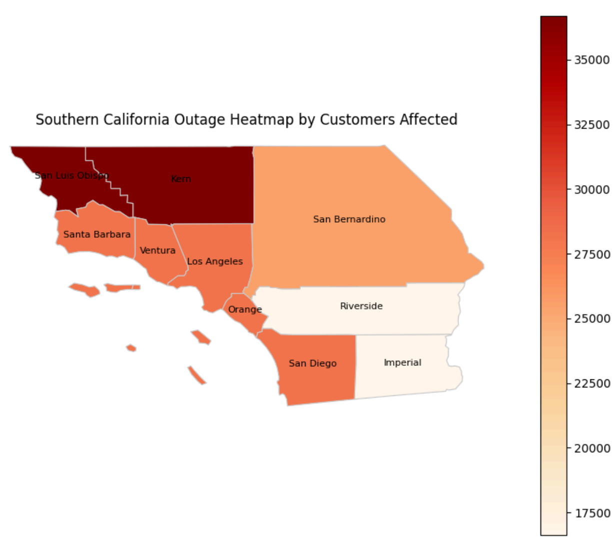
- Coastal: Los Angeles, Orange, San Diego, Ventura, and Santa Barbara
- Mountain: San Bernardino
- Desert: Riverside and Imperial
- North: Bakersfield and San Luis Obispo



Taking a first look at Figure 2, this tells us that the North regions are the most problematic in terms of the Number of Circuit Outages.

This general trend indicates that the circuits in the North Regions are the most problematic, while the circuits in the Desert are the least problematic.

Fig. 2. Southern California Heat Map by Circuit Outages



Taking a look at Figure 3, it has almost the same trend as the previous heatmap; the more circuit outages, the more customers are affected.

In terms ranking importance of which regions to focus on:

1. North
2. Coastal
3. Mountain
4. Desert

Fig. 3. Southern California Outage Heatmap by Customers Affected

Our next step was to statistically analyze the data. We wanted to find statistically significant evidence on whether there is a true difference between each region, and then if there is a true difference between each circuit within each region in terms of Customers Affected.

To execute this, we conducted multiple chi-square tests for homogeneity. The purpose of this test is to check whether the distribution of a categorical variable is equally distributed, evaluating whether the observed frequencies in each category differ significantly from what we would expect under a given hypothesis. Since we are checking significance for the regions, we would assume that each region is equal in terms of Customers Affected. Furthermore, we are going to take the average customers affected instead of the total count of customers affected to account for the repetition in the data. For example, the circuit Orange only covers 1299 customers, but affects a total of 2,547 customers with their 3 outages. By taking the average, we are avoiding the repeated people accounted for in the data.

Before we could start the chi-square test, we needed to check off the assumptions to make sure that the test would be valid. The assumptions for a chi-square test are:

1. **Independence Between Groups**: Frequency/Counts from each category must be independent from each other – 200 customers affected in the desert region were not because of the 50 customers affected in the mountain region.
2. **Categorical Data**: Data must be counts or frequencies for categories – no continuous values nor percentages.
3. **Expected Values should be GREATER than 5:** In chi-square testing, expected values should be greater than 5 to ensure the accuracy and validity of test results. The threshold is based on the reliance of chi-square testing on the central limit theorem.

Since we are going to test the average customers affected per region, all assumptions are checked off, and a chi-square test is valid!

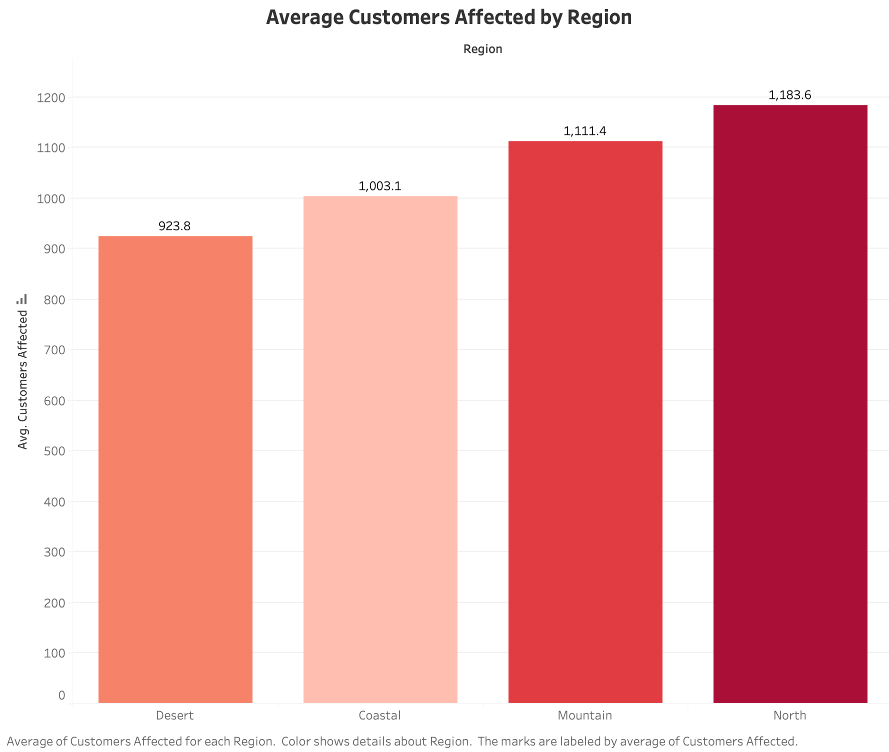


Fig. 4. Average Customers Affected by Region

Figure 4 represents the data that we are going to run the chi-square test on.

The chi-square test returned a p-value of 3.537852e-08.

With that information, we reject the null hypothesis – average customers affected are equally distributed among the regions.

Hence, we can conclude that the region of outages matters in terms of affecting customers.

The chi-square test also provides residuals that we can use to analyze. A residual indicates the distance between the actual value and the expected value. A negative residual shows that the category was below the expected value, while a positive residual shows that the category was above the expected value. In addition, when the absolute value of a residual is greater than 3, that provides strong evidence against the null hypothesis.

Table. 1. Regions Residual Table

Coastal	Desert	Mountain	North
-1.6126	-4.0526	1.7217	**3.9434**

So from this table, we can see that there is a larger significance in the North and Desert Regions, the North having a significant amount of average customers affected **above** the expected values and the Desert having a significant amount of average customers affected **below** the expected values.

Statistically, the only difference from our original findings is that mountain and coastal areas should be swapped. The Coastal and Mountain regions don't have residuals above 3, so that shows that they don't provide statistically significant evidence that they vary against the null. Now we know that it is critical to focus on the North circuits to determine which circuit is causing this, and what the main outage causes are for these circuits.

We ran the same process of chi-square tests to test the average customers affected per north region circuit.

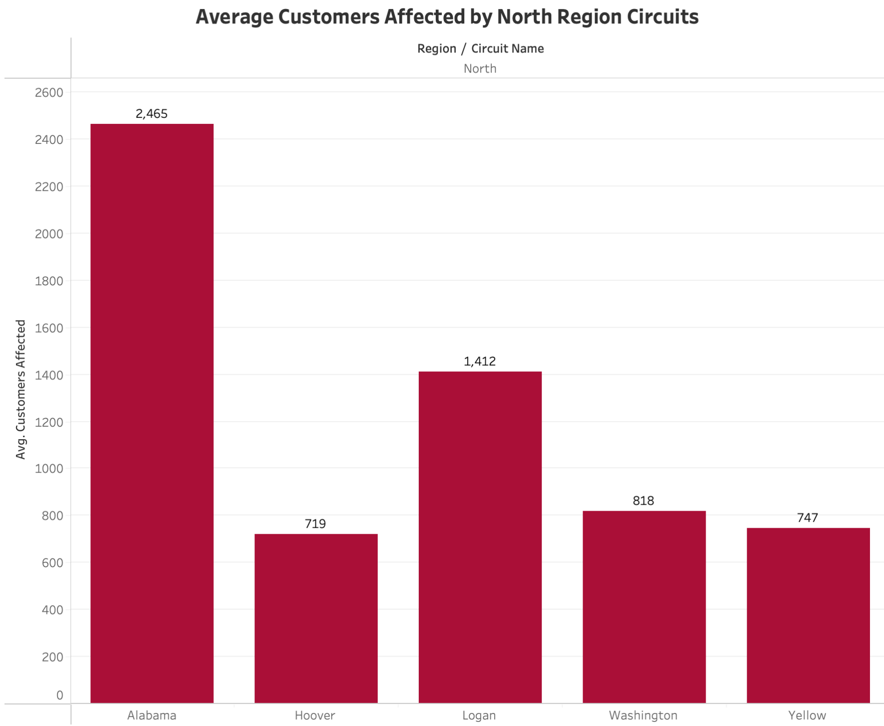


Figure 5 represents the data that will be used to run the chi-square test.

The test returned a p-value of less than 2.2e-16.

Hence, we can conclude that the circuits within the North region matter in terms of affecting customers.

Fig. 5. Average Customers Affected by North Region Circuit

Table. 2. North Region Circuit Residual Table

Alabama	Hoover	Logan	Washington	Yellow
35.1270	-14.6283	**5.1329**	-11.8051	-13.8265

Since Alabama and Logan have significant positive residuals, those circuits are the most critical of all the North region circuits to focus on.

To make sure that Alabama is the absolute most critical circuit, we repeated the chi-square test for the rest of the regions and found the most critical circuit among them. The residual tables are as follows:

Table. 3. Desert Region Circuit Residual Table

Adams	Blue Jay	Gorilla	Monterey	Oregon
-14.6646	**34.2314**	**9.2438**	-14.0061	-14.8045

Table. 4. Coastal Region Circuit Residual Table

Dinan	Green	Jefferson	Orange	Roosevelt
14.8798	**20.1848**	-4.6982	-5.8592	-24.5072

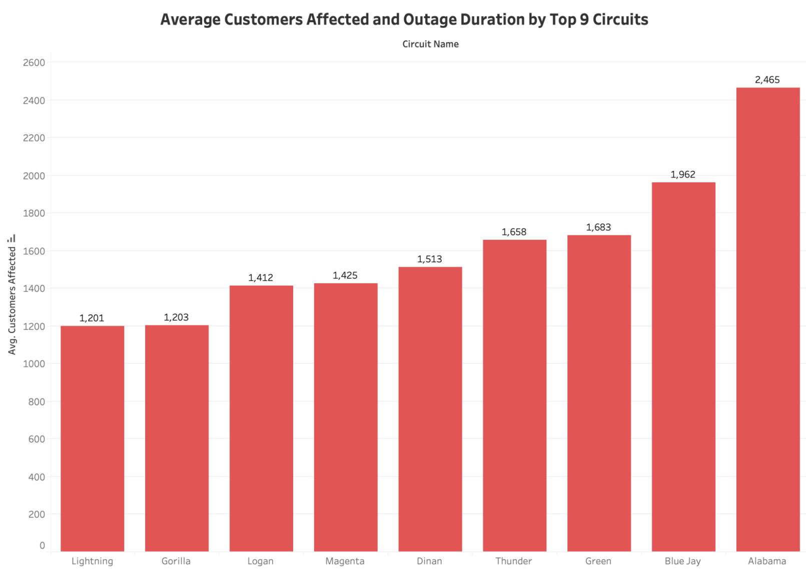
Table. 5. Mountain Region Circuit Residual Table

Grand	Johnson	Lightning	Lincoln	Magenta	Thunder
-24.2099	-2.6656	**5.8767**	-12.1449	**12.9147**	**20.2290**

So out of all the regions, the most critical circuits to focus on are:

- Desert: Blue Jay and Gorilla
- Coastal: Dinan and Green
- Mountain: Lightning, Magenta, and Thunder

Now that we have figured out which circuits in each region are the most significant, we compared those circuits to each other:



This bar plot represents the data that will be used to run the chi-square test.

The test returned a p-value of 1.03576e-165.

Hence, we can conclude that there is a statistically significant difference between circuits.

Fig. 6. Average Customers Affected by Top 9 Circuits

Table. 6. Top 9 Circuits by Average Customers Affected Residual Table

Lightning	Gorilla	Logan	Magenta	Dinan	Thunder	Green	Blue Jay	Alabama
-10.271	-10.218	-5.013	-4.692	-2.514	1.106	1.733	**8.674**	**21.196**

Alabama and Blue Jay are the most significant circuits throughout ALL regions.

2. Understanding the Circuit Outage Causes and Their Effects

To explore how different outage causes relate to outage duration, we plotted the total number of minutes each cause has contributed. From the figure below, it is evident that UG Equipment Failure contributes the most minutes of outage in the entire dataset. However, it is important to note that UG Equipment Failure also has the most number of outages in the data.

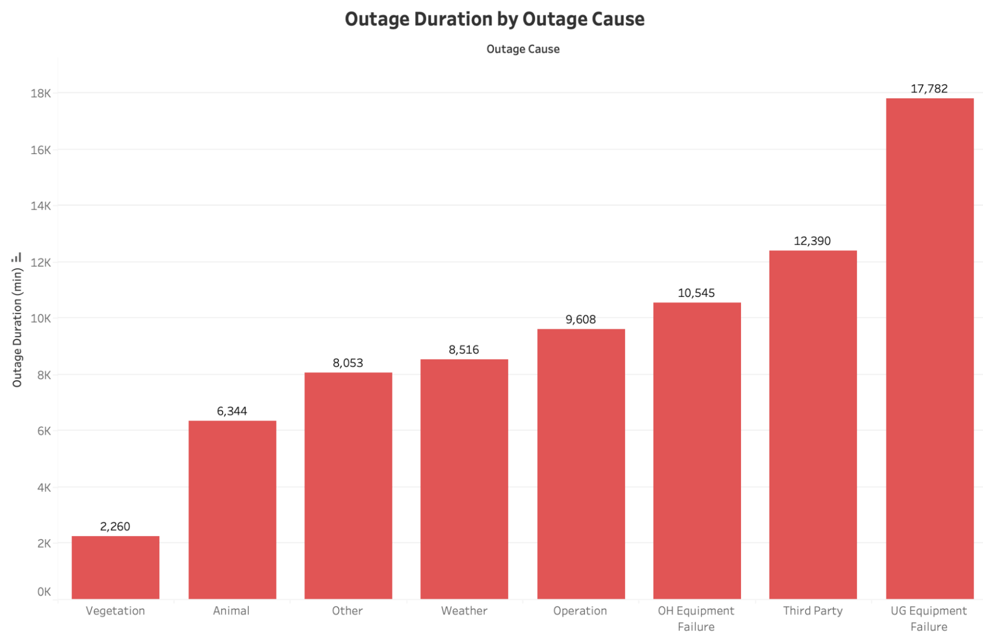


Fig. 7. Total Minutes of Duration vs. Outage Cause

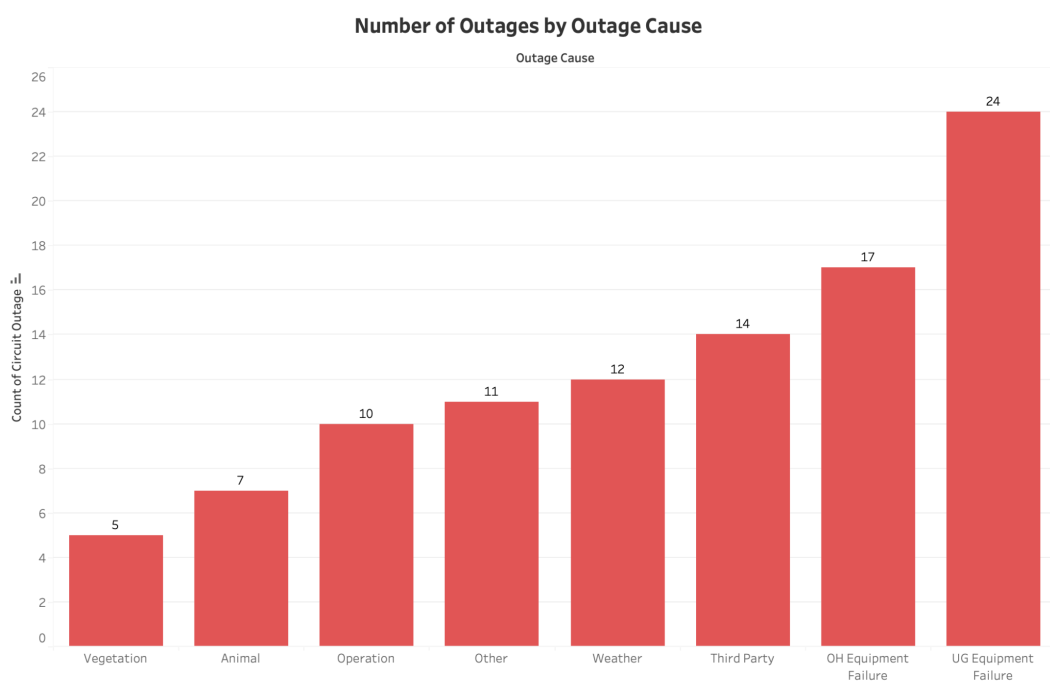


Fig. 8. Number of Outages by Outage Cause

From Fig. 7., we can conclude that UG Equipment Failure is the most problematic cause in terms of Outage Duration, and we should focus on repairing those first. Consequently, OH Equipment Failure and Third Party also cause the most minutes of outages, while also being in the top 2 and 3 of the most number of outages caused (from Fig. 8.).

Since we want to figure out which regions to focus our repairs to, we compared the amount of outages caused by each element and which specific regions they belong to. There are many things to take away, for example, weather affects all four regions equally. Likewise, outages caused by Animals and Vegetation do not differ from each other as much.

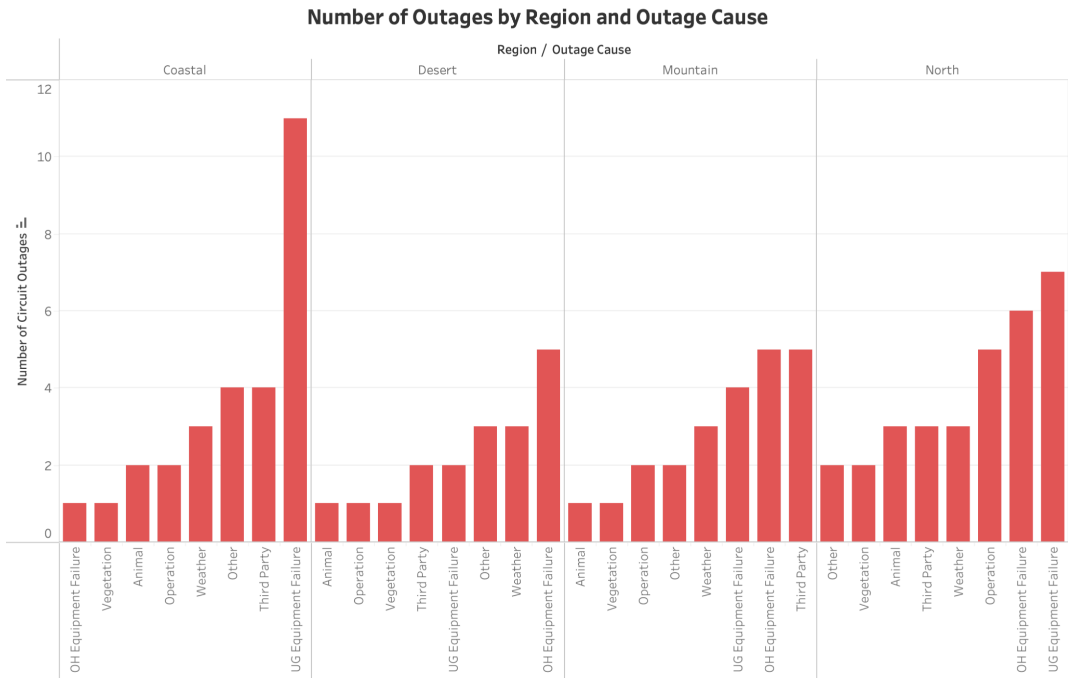


Fig. 9. Number of Outages compared to Outage Cause by Region

Looking at UG and OH Equipment failure, we can see that they are prominent in the Northern area, further supporting our analysis from section 5.1. Additionally, we can conclude equipment repairs for UG Equipment in the Coastal and North areas, and focusing repair for OH Equipment in the Northern Area as well.

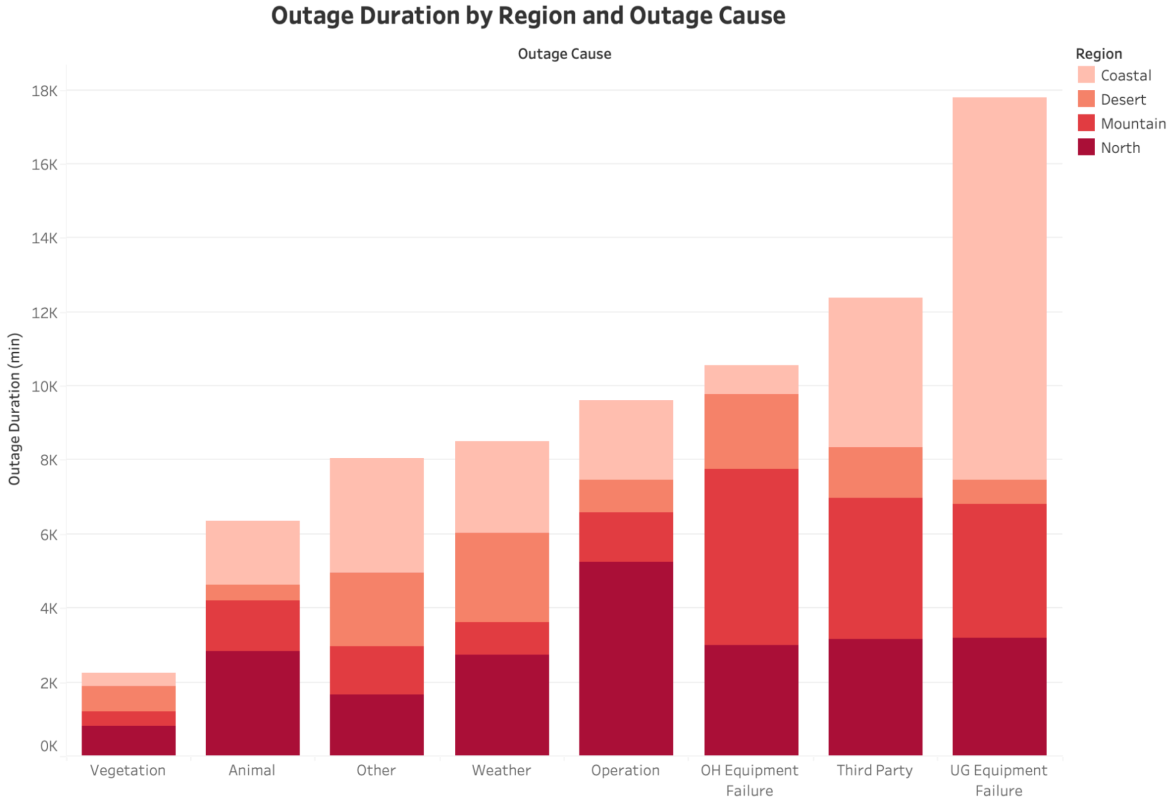


Fig. 10. Outage Duration by Region and Outage Cause

Looking deeper into the actual duration of such outages, we can also conclude that North has the most consistent numbers for the top three most outage causes present in the data set. The mountain areas also show long durations of outages, and therefore should also be accounted for. We can definitely conclude that UG Equipment repairs are necessary for the Coastal Area, while OH Equipment repair is not as necessary.

3. Understanding Circuit Components in Different Regions

Different regions would have their own causes due to the nature of each region. We wanted to find what are the main factors of the circuit we can change in each region – KV, Overhead miles, Underground miles, etc. – so that the circuit would function in the most functional way.

3.1 North Region

The North region of Southern California consists of San Luis Obispo and Kern County. They experience a Mediterranean climate with mild, wet winters and warm, dry summers. During the summer, the temperatures fluctuate with a low of 70ºF to a high of 80ºF during the daytime and 60ºF to 70ºF overnight. During the winter, the temperatures stay generally mild as well where the temperature fluctuates from low 40ºF to low 70ºF. In addition, this region is home to a diverse amount of wildlife and is also a major agricultural hub. Taking these factors, into account, they would explain the outage causes that are taking place in the area

From Fig. 8., the main outage causes were, UG equipment failure, OH equipment failure, and Operation. This indicates that we should focus on the KV, circuit miles, and KV miles to find the problems within the circuits. We created a linear regression model comparing KV Miles to Number of Outages first, to find any initial trends.

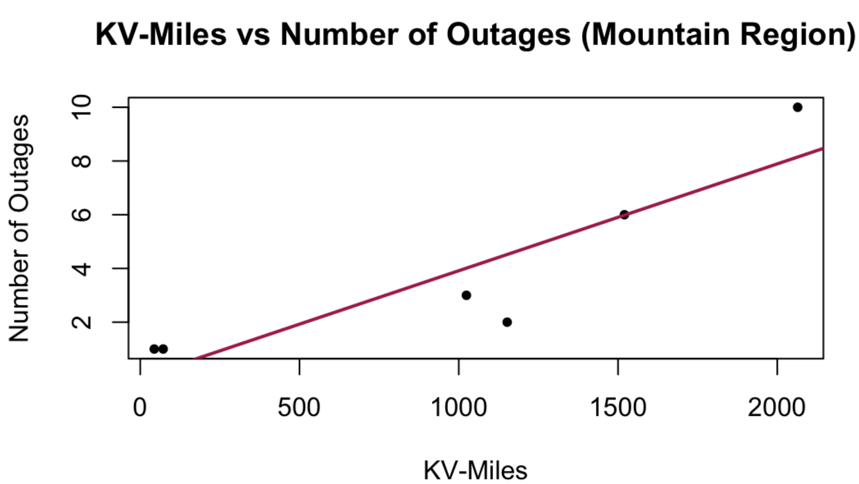
Making the linear regression model produced nothing statistically significant. So, we concluded that the equipment failures and operation causes are independent from the circuit itself, and instead it is affected by the conditions it is in. More of the plan for the northern region will be discussed later in section 7: The Implementation Plan.

3.2. Mountain Region

The Mountain region of Southern California consists of San Bernardino. This region experiences extreme weather during seasons. In the summer, the temperature stays around high 90ºF or higher and is generally dry. In the winter, the temperatures drop to freezing or even below, especially in high elevations. Throughout the year, there are strong, dry winds being pushed through and it is generally rainy during spring and autumn. The mountain region is also home to an even more diverse wildlife, the most common being squirrels, mountain lions, and coyotes. This area is not heavily populated compared to the other regions.

From Fig. 8., the main outage causing the most number of outages were OH equipment failure, Third Party, and UG equipment failure. This tells us that the operation of the circuits should be looked at and that KV and circuit miles will play a large role in the circuit outages. 4 of the circuits are 16 KV and 2 of the circuits are 4 KV.

To find what we should focus on, we created a linear regression model comparing the KV Miles and Number of Outages. The results from this would help us to pinpoint what we should mainly focus on and fix for the circuits in the Mountain region.



Intercept: -0.06

- Relatively, at 0 KV-Miles, there would be -0.06 Outages.

Slope: 0.0039

- As KV Miles increase by 1000 units, the number of outages increase by 3.9.

R-squared: 0.8059

- 80.59% of the variability in Number of Outages can be explained by the KV Miles.

Fig. 11. KV-Miles by Number of Outages (Mountain Region)

F-statistic p-value: 0.015; this model is significant at an alpha level of 0.05.

From this regression, we need to take a deeper look into each circuit in the mountain region to determine the individual fixes each circuit needs. From table. 5., The most problematic circuits were Lightning, Magenta, and Thunder in terms of customers affected, so we will take a deeper look into just those three circuits.

Table. 7. Significant Circuits from Mountain Region Circuit Information

Circuit Name	Customer Count	KV	Circuit Miles	KV Miles	Number of Outages
Magenta	2367	16	129	2064	10
Thunder	3945	16	72	1152	2
Lightning	3591	4	18	72	1

The summary of this table:

- **Lightning**: Only had one circuit but affected the most customers was because of how many customers they served. So in terms of the number of outages, Lightning isn't significant to fix.

- **Thunder**: Similar to lightning, Thunder only has 2 circuit outages, but since it has a significantly large amount of customers they serve, they were shown to be more significant in our previous data analysis. In terms of the number of outages Thunder isn't significant to fix.

- **Magenta**: Has the most number of outages and the longest circuit miles out of all mountain region circuits. The best fix for Magenta is to decrease the circuit miles to decrease the KV miles which will ultimately decrease the number of outages.

3.3 Coastal Region

The Coastal region of Southern California consists of Santa Barbara, Ventura, Los Angeles, and Orange County. This region experiences a Mediterranean climate with warm, dry summers and mild, wet winters. The average annual temperature ranges between 50ºF to 65ºF. The summer can have more extreme heat, with average highs around 70ºF to 80ºF. Winter remains mild, around the same temperature of mid 50ºF to low 60ºF, however, winter does bring most of the rain. The coastal region experiences various winds throughout the year as well. This area is one of the most populated in Southern California and seagulls, various birds, and squirrels are often spotted in this area as well.

From Fig. 8., the main outage causing the most number of outages are UG equipment failure, Third Party, and Other. There is a prominent amount of UG equipment failure which could be explained by coastal flooding, corrosion, sea-levels. These factors of the coast easily damage the underground infrastructure.

Making a linear regression model comparing underground miles and number of outages showed nothing statistically significant nor did comparing underground KV miles and number of outages. So, we concluded that the UG equipment failure is independent from the circuit itself, and instead it is affected by the conditions it is in. More of the plan for the coastal region will be discussed later in 7. The Implementation Plan.

3.4 Desert Region

The Desert region of Southern California consists of Riverside and Imperial County. This region is heavily characterized by its extreme, hot and dry weather throughout the year. Hitting a high temperature of over 110ºF and rarely dropping below 90ºF during the summers. Winters have cooler and milder weather staying in the 60ºF range all day. These areas are not as highly populated as the other regions and the animals that are commonly found here are snakes and various birds.

From Fig. 8., the main outage causing the most number of outages were OH equipment failure, Weather, and Other. Since OH equipment failure caused the most number of outages, we created a linear regression model comparing Overhead miles to Number of Outages and Overhead KV miles to Number of Outages to find any significant trends.

Similar to the Coastal region, there were no statistically significant trends showing. We concluded that the OH equipment failure is independent from the circuit itself, and is affected by conditions other than the circuit. More of the plan for the Desert region will be discussed later in 7. The Implementation Plan.

4. SAIFI and SAIDI Analysis

The SAIFI and SAIDI are good measures that can indicate overall trends. To reiterate, the SAIFI is calculated by dividing the number of outages by the amount of customers served, and the SAIDI is calculated by the average amount of outage duration by the total number of customers affected. To understand the distribution of customers that is served by the IBEC, the pie chart shows the percentage of customers per region. IBEC serves a total of **45,321** customers, the majority of which reside in the mountain region. For the sake of our analysis, one of our presumptions would be that IBEC serves the same amount of customers for both 2023 and 2024. This helps us narrow down some trends within the data.

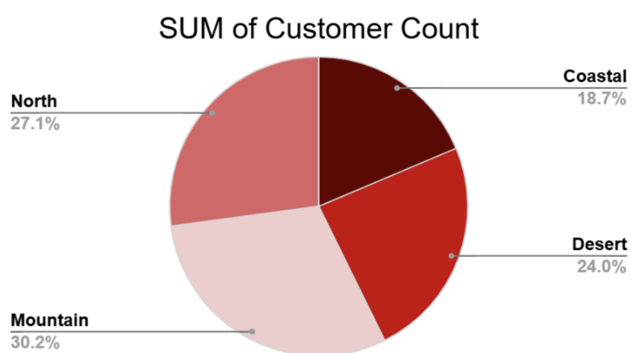


Fig. 12. Pie Chart of the Customer Count per Region

4.1 Comparing 2023 and 2024

The SAIDI for 2023 is given in the original dataset, and using the rest of the data for 2024, we were to calculate the values for SAIDI for 2024. Since we want a lower SAIDI, we can compare the value for

2023 and 2024. The bar chart below shows a side by side comparison for each circuit, with an obvious spike for the circuit “Roosevelt”. Besides the spike, there is also a visual significance in the increase for the same circuit.

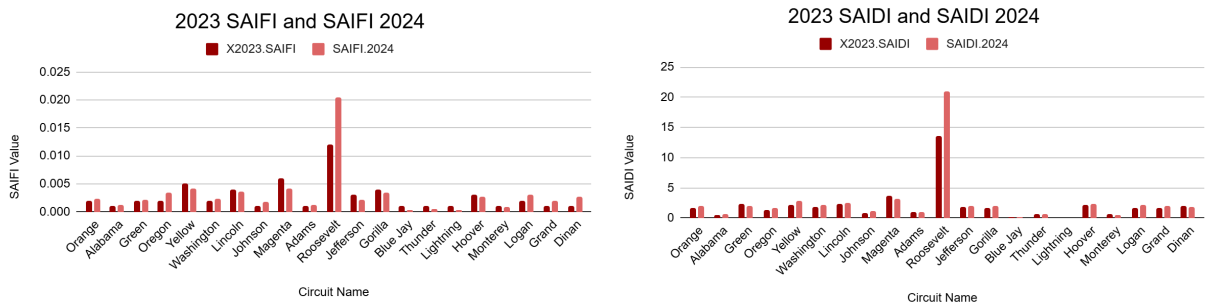


Fig. 13. Comparisons of 2023 and 2024 SAIFI and SAIDI

We are also interested in the overall performance of each circuit between the two years, we took the difference of each and graphed the results. A positive result shows that the average number of minutes of outage duration increased per customer, while a negative result shows the opposite.

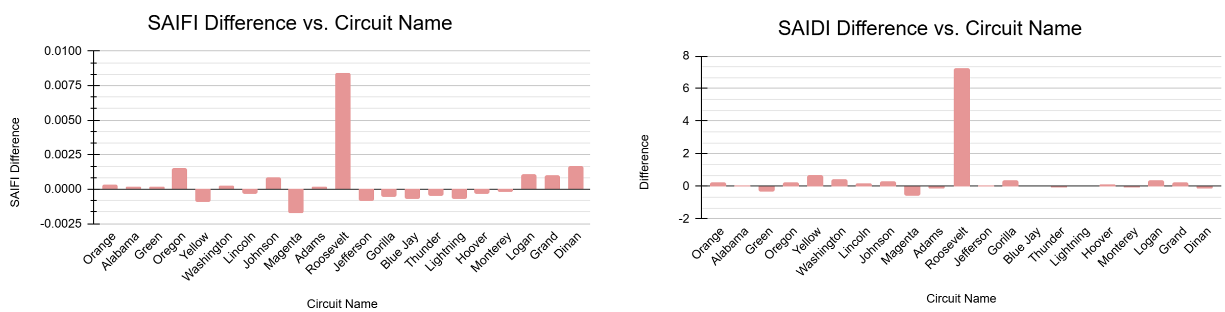


Fig. 14. SAIFI and SAIDI differences by Circuit Name

4.2 Difference and Regional Analysis

In order to understand the trends, we calculated the difference between the two years. A positive difference means that 2024 had a higher SAIFI/SAIDI than 2023, which shows that the circuit performed worse in 2024. This was an attempt to eliminate the spike in the circuit ‘Roosevelt’. However, we get the same spike on the circuit Roosevelt. This shows that the circuit performed much worse compared to other circuits that only worsened or improved much less. Looking into the specific regions these improvements and degradation happened, the graphs below visually shows which regions have been improving. In this analysis,

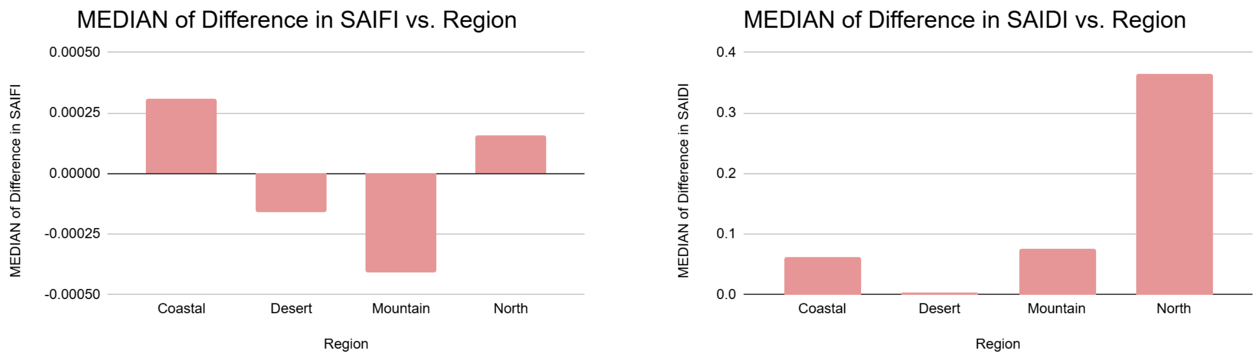


Fig. 15. Median of the Difference of SAIFI and SAIDI by Region

we chose to use the measurement of the median since it is not affected by outliers. Simply removing the specific outliers might cause the data to shift. These graphs show that the Coastal and Northern region are experiencing more outages in 2024 compared to 2023, while the Desert and Mountain regions are experiencing less amounts of outages. We want to keep in mind that this only accounts for the number of outages, not the duration. Additionally, the Northern region has a significant spike in SAIDI, showing that the duration of outages that happen in the northern region in 2024 are much higher than the duration of its outages in 2023. The regional analysis helps us understand which regions we want to focus on. In this case, the Northern region is the most problematic, followed by the Coastal region.

5. Customer Minutes Interrupted Trends

We analyzed the average outage minutes a customer experiences to determine which circuits need to be focused on. This is the secondary method to find which circuits should be focused on.

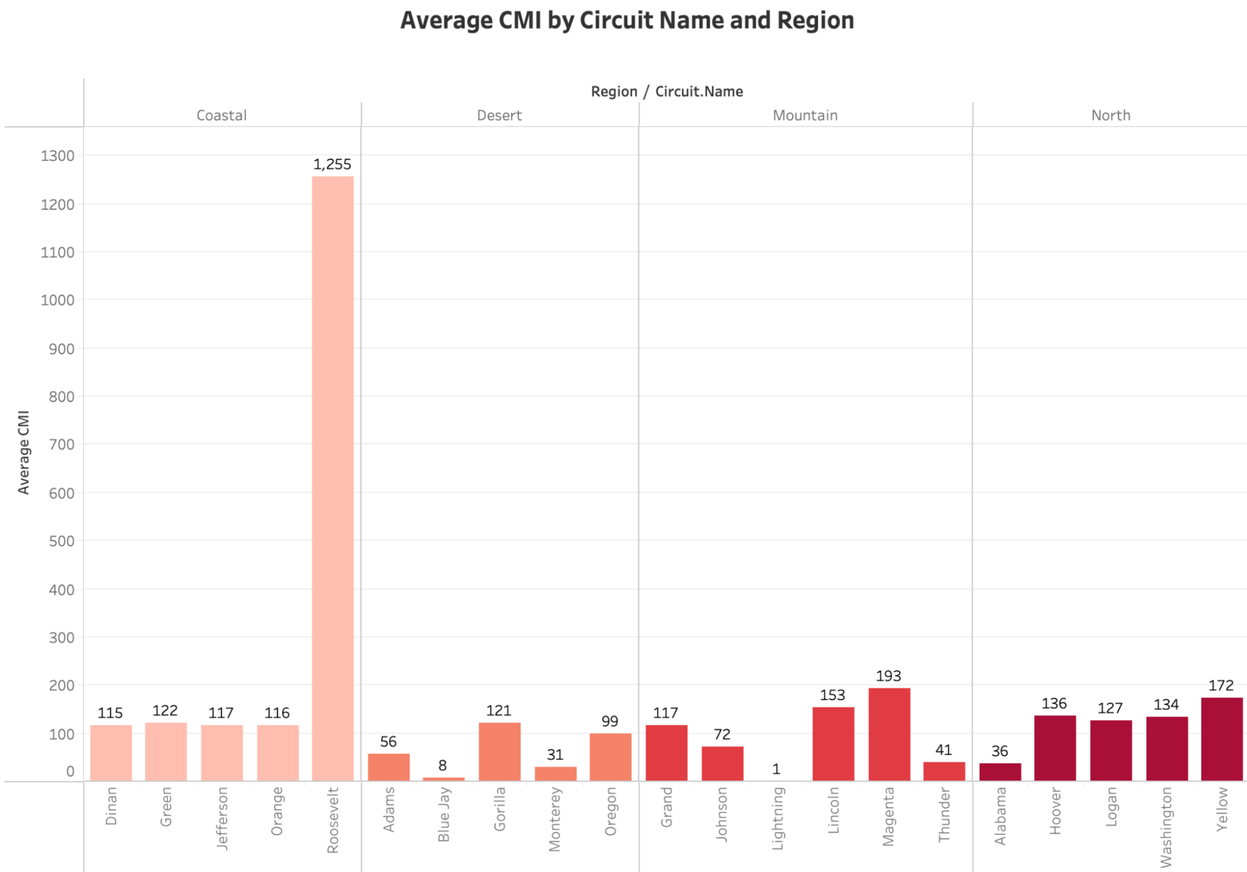


Fig. 16. Average CMI by Region and Circuit Name

For the Coastal region, Fig. 16. shows that on average, a customer served under Roosevelt experiences 1255 minutes of outage. The rank of coastal circuits goes from Roosevelt, Green, Jefferson, Orange, then Dinan

For the Desert region, the rank of the circuits goes from Gorilla, Oregon, Adams, Monterey, then Blue Jay

For the Mountain region, the rank of the circuits goes from Magenta, Lincoln, Grand, Johnson, Thunder, and then Lightning.

For the North region, the rank of the circuits goes from Yellow, Hoover, Washington, Logan, and then Alabama.

BUSINESS STRATEGY

1. Objective Alignment & Value Proposition

Overall, our clear and concise goal is to **reduce the customer minutes of outages** by implementing necessary equipment upgrades and providing safe and reliable solutions to power outages. Consequently, we expect to **optimize the allocation of budget and improve customer satisfaction**.

We look into high impact regions and perform targeted upgrades for maximum reliability gain. Additionally, we want to perform predictive analysis for the likelihood of outages as a form of proactive maintenance risk reduction.

2. Strategic Recommendations

We recommend performing different solutions and plans **depending on the region of certain circuits**. In general, we want to maintain the health of our circuits, employees, and budget. We also want good customer feedback and better data collection in the future. More details can be found in sections 3.4 and 3.5 of the Implementation Plan.

2.1. The Northern Region

The Northern region is the most problematic of all the regions. It has the most number of outages, the most customers affected, and the most change from the SAIDI in 2023 and SAIDI in 2024. Of all the causes, UG and OH Equipment failure are the most prominent, followed by Operation, with Operation having the longest duration.

- **Major Equipment Upgrades**: Since all the causes for the outages are equipment and operational, repairing and replacing aging transmission will benefit the overall performance of each circuit.
- **Improved dispatch outage response time**: Since operational causes create the longest outage durations, having a quicker response time would severely decrease how long each outage can last. Combined with the allocation of the budget into the repairs, we could drastically decrease the CMI for North.
- **Strategic Priority**:
    1. Alabama: Using Table 2, it is clear that Alabama severely affects a lot of customers. Although it had the lowest CMI score in the northern region, we want to prioritize the effect of the outages over the duration.
    2. Yellow: According to our CMI bar graph (Fig. 16), Yellow has the highest score. Although they do not affect a lot of people compared to the other circuits, these outages are a negative outlook on the company's services.
    3. Logan: In Table 2, Logan had the second highest residual, which suggests that they affect more people than expected. Logan also has the second highest CMI between the circuits. This suggests that we want Logan to be a focus, but not the first choice.
    4. Washington & Hoover: Both of these circuits affect less people compared to the other circuits in the region. Additionally, they are 3rd and 4th in terms of CMI score. Therefore, they can be prioritized last when making business decisions.

2.2. The Coastal Region

The coastal region serves about 8,495 customers, the least out of all customers. However, it has the second most problematic circuits based on region and customers affected in the entire data set. In this region, Underground Equipment Failure and Third Party outages are the top causes for the majority of the outages. Additionally, according to our analysis of the SAIFI, it posed the most negative change from 2023 and 2024 SAIFI data.

- **Major UG Equipment Repairs**: Since UG equipment failure is one of the main reasons for power outages, we want to allocate our budget into improving these equipment.

- **Protective Infrastructure**: Referencing 3.3 of Data Analysis and Insights, we want to prevent the equipment malfunctions in order to reduce the amount of repairs needed. We can do this by applying tide gates into the coastlines which can reduce the corrosion and flooding. Considering that UG Equipment Repairs are much more expensive than OH Equipment repairs, we want to implement the prevention in order to reduce costs.

- **Roosevelt Plan**: The circuit Roosevelt is an obvious outlier for our data set. This is evident in the SAIFI and SAIDI analysis, the CMI trends, and the kV and Circuit Miles analysis sections. Given in the data set, we saw that Roosevelt had the least amount of customers served, but the most number of circuit outages. This can be approached in two ways:

    1. Prioritizing Budget: We propose cancelling services for the circuit Roosevelt. We would end up spending more on repairs, since they mainly have UG Equipment Failure. We wouldn't be affecting a lot of customers, but it might receive negative feedback by the public.

    2. Prioritizing Customer Satisfaction: We propose sending a case worker to the Roosevelt circuit to further collect data and analyze why they are an outlier. This will be received well by the public, increase loyalty from the customers, and collect more data for future use. However, sending a case worker and repairmen would ultimately cost more.

- **Strategic Priority**: For prioritizing the rest of the circuits, we want to base them off of the number of customers affected using our chi-sq test since they all have relatively the same average CMI – Dinan: 115, Green: 122, Jefferson: 117, Orange: 116. In Table 4, we can see that our priorities are as follows: Green, Dinan, Jefferson, then Orange.

2.3. The Mountain Region

The Mountain region consists of Grand, Johnson, Lightning, Lincoln, Magenta, and Thunder with Lightning, Magenta, and Thunder being the most significant circuits in terms of Customers Affected and Magenta being the most significant circuit overall.

The main causes for the mountain region were Third Party, OH Equipment Failure, and UG Equipment Failure with OH Equipment Failure causing the longest Outage Duration.

There are a total of 13,678 customers served and an average of 1,111 customers being affected.

Trends were found relating the KV-miles to the number of outages: For every 1000 unit increase in KV-Miles, the number of outages increased by 3.9.

Strategic Priority:

1. Magenta: Reduce the circuit miles. Magenta has the longest circuit but doesn't serve the most people, making its circuit miles redundant. Hence, decreasing the circuit miles, will decrease the KV miles, which will ultimately decrease the number of outages. Magenta also has the largest average CMI of 193 minutes; by decreasing the number of outages, the average CMI will also decrease.

2. Lincoln: This circuit ranked second in terms of number of outages and average CMI. Although it wasn't one of the circuits that were found significant through Customers Affected, those other factors relatively makes it the second most important circuit in the mountain region.

3. Johnson: This circuit ranked third and fourth for number of outages, 3 outages, and average CMI, 72, respectively. Since it had more outages than Grand, we found it to be more important even though it doesn't have a higher CMI.

4. Grand: This circuit ranked third in terms of average CMI, 117 minutes, but only had one circuit outage; caused by OH equipment failure. Specifically at this circuit, minor OH repairs should be done.

5. Thunder: Although found significant in terms of Customers Affected, this circuit had one circuit outage and the second lowest average CMI of 41. Those factors overrode the fact that it was one of the circuits that affected the most customer.

6. Lightning: Also found significant in terms of Customers Affected, this circuit was found to only have one outage and to have the lowest average CMI of 1 minute. Those factors overrode the fact that it was one of the circuits that affected the most customers.

2.4. The Desert Region

The Desert regions pose the least problematic out of all the outages, from the analysis, it is evident that desert circuits pose the least amounts of outages and the least region of affected customers. Additionally, causes like Overhead Equipment failure, the weather, and other factors cause the majority of the outages happening in the desert region.

With a total population of 10,893 customers served, solutions that we can implement for the desert region includes setting up the following:

- **Back-up generators**: since the 2nd most prominent cause for the desert region is caused by weather, we can help our customers be prepared for outages that are out of our control.

- **Solar Panels**: by installing solar panels, we take advantage of the location while reducing the amount of power each circuit needs to use.

- **Minor Overhead Equipment repairs**: minor repairs can improve how long each outage can last. This improvement is cheap and timely, but also ensures that the duration of each outage is addressed. More details on what kind of repairs can be done in

- **Improved dispatch outage response time**: By improving the dispatch response time, we are improving customer satisfaction as well as reducing the duration of the outage. More details are found in section 3.3 of the Implementation plan.

- **Strategic priority**: For the desert region, we want to prioritize the circuits in a specific order.

    1. Blue Jay: This circuit shows the most discrepancy in the amount of customers affected based on Table 6. Since we prioritized improvements in the duration, our second decision branch will be based on the customers affected.

    2. Gorilla: Similar to Blue Jay, Gorilla also has a positive residual based on Table 3. In addition, this circuit ranks highest in priority in terms of the average minutes a customer experiences.

    3. Oregon and Adams: These 2 circuits had very similar residuals based on Table 3, meaning they affect almost the same amount of customers. They are also similar in terms of CMI, 99 minutes and 56 minutes respectively.

    4. Monterey: This circuit had relatively the same residual as Oregon and Adam as well based on Table 3, which tells us that it affected almost the same amount of customers as them. This circuit ultimately ranks last in importance since it had one of the lowest CMI of 31 minutes.

IMPLEMENTATION PLAN

1. Executive Summary

IBEC is an established company in the United States with a substantial clientele to support them. They manage and control circuits across the country that provide ample services to their customers. In order to move their business to the next level, IBEC would like to effectively deal with, reduce, and mitigate circuit outages in a manner that would reduce losses and improve service delivery to their customers. This plan outlines the methods through which IBEC can accomplish their goals by optimizing their resources, efficiently responding to issues, and taking preemptive steps to prevent problems before they arise.

2. Goals & Objectives

Our specific goals for improvement are as stated:

- Reduce the number of circuit outages that are occurring
- Make a solid plan to identify where to allocate funds
- Establish and train teams to begin repairing the most critical circuits
- Maintain well performing circuits to prevent outages due to deterioration
- Improve customer satisfaction

3. Key Implementation Areas

3.1 Infrastructure Modernization

Objective: Reduce the number of circuit outages by updating outdated circuit components to obviate the need for replacement.

- Create a schedule to minimize service downtime for customers
- Replace older transformers and cables in high loss areas
- Upgrade components within existing switchgear with modern, high-efficiency alternatives
- Modernize network protectors to improve the reliability and security of underground utility systems
- Incorporate microprocessor based digital relays and smart meters to provide real time data

Responsible Departments & Teams

- Engineering Department
  - Electrical Design Team
  - Power Systems Team
  - Control Systems Team
  - Renewable Energy Team
  - Research and Development Team
- Projects & Construction Department
  - Project Management Team
  - Site Execution Team
  - Commissioning Team
  - Quality Assurance & Control Team

3.2. Strategic Budget Allocation

Objective: Make a solid plan and identify where the budget is to be allocated based on the loss from circuit outages and the type of improvements that need to be made.

- Identify the circuits that are contributing the most to loss
- Create a hierarchy of the types of improvements that need to be made, beginning with repairs and going up to upgrades or transformations of entire circuits–if necessary
- Recognize the key components of the circuits leading to the loss and measures that need to be taken to fix such components
- Work through the hierarchical list to tackle tasks that require the most attention first, making sure there is enough money in the budget for important issues
- As items on the list are completed, the most important circuits have their portion set aside, and less critical tasks can be selectively chosen based on what is left of the budget or if any circuit moves up the hierarchy and needs to be dealt with

Responsible Departments & Teams

- Financial Department
  - Electrical Design Team
  - Budgeting & Forecasting Team
- Project Management Department

  - Project Management Team
- Operations & Maintenance Department

3.3. Circuit Repair Team and Deployment

Objective: Train and deploy a team of experts to begin repairing circuits from most critical to least.

- Find engineers that are open to travelling to various circuit locations for a certain period of time
- Analyze the list of problematic circuits and their order of importance based on models provided by the consulting team
- Categorize engineers based on expertise and interest and train multiple teams at a time to fix specific types of circuit failures
  - Considering the biggest issue IBEC has to deal with is underground circuits, train a majority of engineers to repair this type of circuit first
- Once training is complete, assess how much manpower is needed at the top three circuits and assign one or more teams to each circuit based on the assessment
- While each team member is deployed, continue training a new batch of engineers based on the next repair site.
- After a team is done repairing a circuit, they will be assigned to another circuit on the list or continue training with another type of circuit

Responsible Departments & Teams

- Engineering Department
  - Electrical Design Team
  - Power Systems team
- Projects & Construction Department
  - Project Management Team
  - Site Execution Team
- Operations & Maintenance Team
  - Repair Team
- Human Resources Department
  - Training & Development Team
- Legal & Contracts Department
  - Contract Review Team
  - Dispute Resolution Team

3.4. Circuit Health Maintenance

Objective: Create regular maintenance plans and small teams to visit circuits on a regular basis to ensure each circuit is receiving appropriate care.

Tasks:

- Conduct weekly visual inspections to identify physical problems in the infrastructure
- Designate a day for weekly electrical tests including the insulation resistance test, contact resistance test, over-potential test, and circuit breaker timing test

- Every month send out a team to lubricate all moving key components and clean contacts of a circuit
- Twice a year, calibrate settings to ensure the circuit breaker operates in the proper sequence
- Maintain a facilities management checklist for each circuit that is reported to upper level management

Responsible Departments & Teams:

- Operations and Maintenance Department
    - Preventative Maintenance Team
    - Breakdown/Repair Team
- Construction Department
    - Site Execution Team
    - Quality Assurance & Control Team

3.5. Customer Experience Improvement

Objective: Improve customer satisfaction by being transparent about repairs and outlining specific steps being taken to prevent future outages.

Tasks:

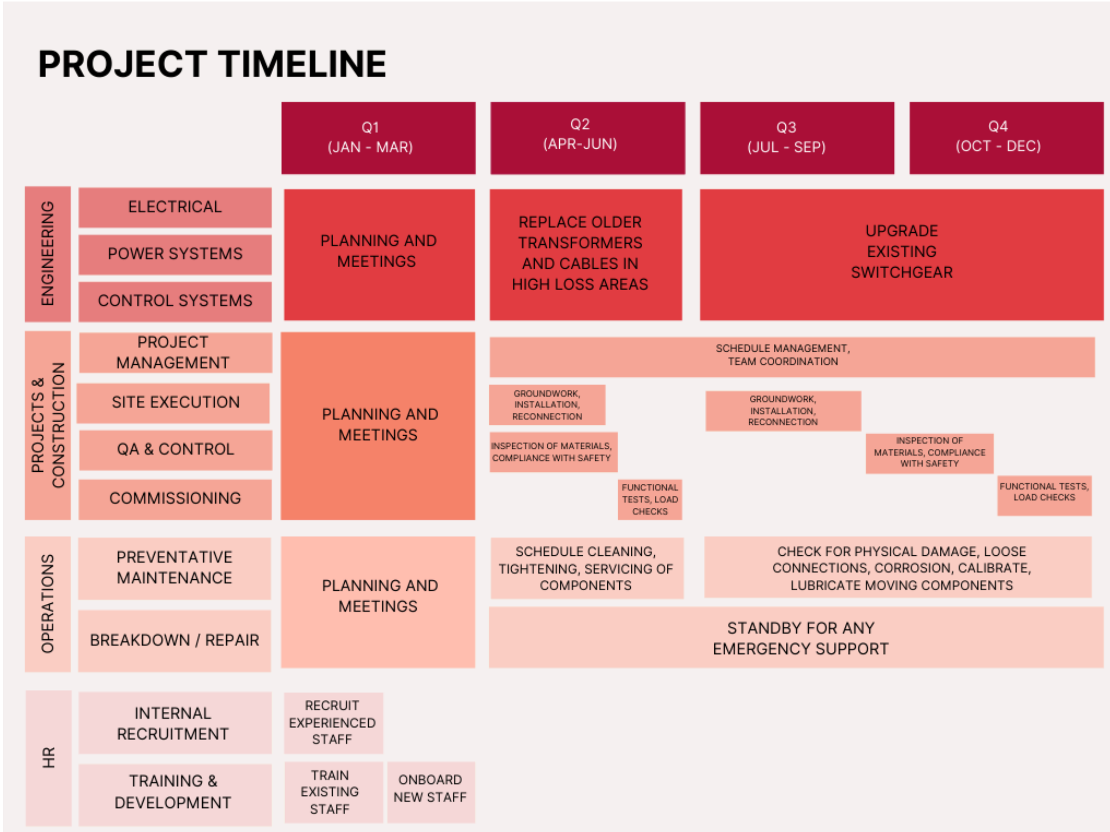
- Collect customer feedback post-outage and analyze responses
- Create an online forum for customers to be able to communicate with each other and provide testimonials about their experience with IBEC
- Have a customer service team member
- Provide a resources page on the company website so customers can find steps they need to take when an outage occurs

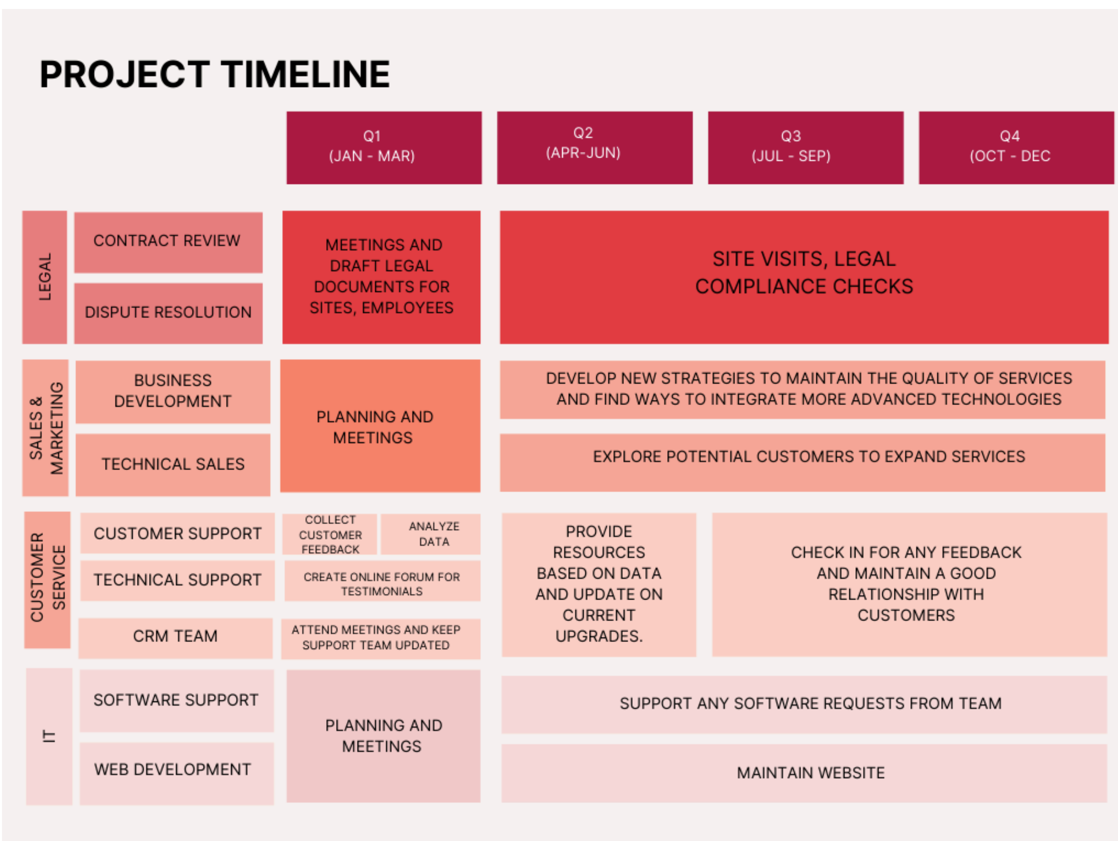
Responsible Departments & Teams:

- Sales & Marketing Department
    - Business Development Team & Technical Sales Team
- Customer Service Department
    - Customer and Technical Support Team
- IT Department
    - Software and Web Development Support Team

3.4. Timeline

This is our proposed timeline to implement for the future. It has a plan for each team throughout a year, assuming the improvement project starts in January.


PROJECT TIMELINE
Q1 (JAN - MAR)
Q2 (APR-JUN)
Q3 (JUL - SEP)
Q4 (OCT - DEC)
ENGINEERING
ELECTRICAL
POWER SYSTEMS
CONTROL SYSTEMS
PLANNING AND MEETINGS
REPLACE OLDER TRANSFORMERS AND CABLES IN HIGH LOSS AREAS
UPGRADE EXISTING SWITCHGEAR
PROJECTS & CONSTRUCTION
PROJECT MANAGEMENT
SITE EXECUTION
QA & CONTROL
COMMISSIONING
PLANNING AND MEETINGS
SCHEDULE MANAGEMENT, TEAM COORDINATION
GROUNDWORK, INSTALLATION, RECONNECTION
GROUNDWORK, INSTALLATION, RECONNECTION
INSPECTION OF MATERIALS, COMPLIANCE WITH SAFETY
INSPECTION OF MATERIALS, COMPLIANCE WITH SAFETY
FUNCTIONAL TESTS, LOAD CHECKS
FUNCTIONAL TESTS, LOAD CHECKS
OPERATIONS
PREVENTATIVE MAINTENANCE
BREAKDOWN / REPAIR
PLANNING AND MEETINGS
SCHEDULE CLEANING, TIGHTENING, SERVICING OF COMPONENTS
CHECK FOR PHYSICAL DAMAGE, LOOSE CONNECTIONS, CORROSION, CALIBRATE, LUBRICATE MOVING COMPONENTS
STANDBY FOR ANY EMERGENCY SUPPORT
HR
INTERNAL RECRUITMENT
TRAINING & DEVELOPMENT
RECRUIT EXPERIENCED STAFF
TRAIN EXISTING STAFF
ONBOARD NEW STAFF


PROJECT TIMELINE
Q1 (JAN - MAR)
Q2 (APR-JUN)
Q3 (JUL - SEP)
Q4 (OCT - DEC
LEGAL
CONTRACT REVIEW
DISPUTE RESOLUTION
MEETINGS AND DRAFT LEGAL DOCUMENTS FOR SITES, EMPLOYEES
SITE VISITS, LEGAL COMPLIANCE CHECKS
SALES & MARKETING
BUSINESS DEVELOPMENT
TECHNICAL SALES
PLANNING AND MEETINGS
DEVELOP NEW STRATEGIES TO MAINTAIN THE QUALITY OF SERVICES AND FIND WAYS TO INTEGRATE MORE ADVANCED TECHNOLOGIES
EXPLORE POTENTIAL CUSTOMERS TO EXPAND SERVICES
CUSTOMER SERVICE
CUSTOMER SUPPORT
TECHNICAL SUPPORT
CRM TEAM
COLLECT CUSTOMER FEEDBACK
ANALYZE DATA
CREATE ONLINE FORUM FOR TESTIMONIALS
ATTEND MEETINGS AND KEEP SUPPORT TEAM UPDATED
PROVIDE RESOURCES BASED ON DATA AND UPDATE ON CURRENT UPGRADES.
CHECK IN FOR ANY FEEDBACK AND MAINTAIN A GOOD RELATIONSHIP WITH CUSTOMERS
IT
SOFTWARE SUPPORT
WEB DEVELOPMENT
PLANNING AND MEETINGS
SUPPORT ANY SOFTWARE REQUESTS FROM TEAM
MAINTAIN WEBSITE

5. Risk Assessment and Mitigation

To ensure all these improvements take place with the utmost care and safety for both employees and customers, IBEC must be aware of the risks involved and potential issues that may arise.

5.1 Potential Risks and Risk Assessment

Risk	Type of Circuit	Likelihood	Risk Level
Falls from height	Aboveground	Low-Medium	High
Arc flash (electrical shock)	Underground	Medium	High
Flooding	Underground	Medium	High
Confined space hazards	Underground	Medium	High
Cable connection errors	Underground	Low	Medium
Soil collapse	Underground	Low	Medium
Rodent damage	Underground	Low-Medium	Medium
Access difficulty for emergencies	Underground	Low	Medium-High
Fault lines	Underground	Medium	High
Cable degradation from moisture	Underground	Low	Medium-High
Cable degradation from UV	Aboveground	High	Low
Weather exposure	Aboveground	High	Medium
Nature interference	Aboveground	Medium	Medium
Falling objects	Aboveground	Medium	Medium

5.2 Mitigation Strategies

Risk	Strategy
Falls from height	Wear appropriate personal protective equipment and tool lanyards to prevent injury.
Arc flash (electrical shock)	Wear appropriate personal protective gear, de-energize equipment during maintenance, and maintain a safe distance from energized equipment.
Flooding	Prioritize elevation and flood barriers. Ensure proper drainage systems are in place and working to manage water runoff.
Confined space hazards	Prioritize atmospheric testing and proper ventilation. Provide training for underground entry and ensure there is adequate lighting and communication. Maintain a list of rescue planning protocols for emergencies.

Cable connection errors	Focus on proper installation, regular maintenance, and using high-quality materials.
Soil collapse	Sloping to direct soil weight away from the trench wall, shoring with metal plates to reinforce walls, and shielding with trench shields.
Rodent damage	Seal entry points and use protective barriers with heavy repellent methods like scent based or ultrasonic devices.
Access difficulty for emergencies	Ensure clear and readily accessible entry points are visible, implement signage and marking systems, enhanced system monitoring for disaster prevention.
Fault lines	Implement robust maintenance and monitoring strategies such as flexible foundations, isolating base elements, and ensuring the structure can withstand seismic force.
Cable degradation from moisture	Regularly check for proper installation, use shielding to protect from electromagnetic interference and external influences, and conduct regular testing.
Cable degradation from UV	Use the appropriate cable jackets and cable wraps or sleeves. Conduct regular inspections and maintenance with proper load balancing.
Weather exposure	Protect wiring, connections and equipment using proper drainage, installing ground fault circuit interrupters, and regularly inspecting for damage or corrosion.
Nature interference	Focus on vulnerable areas and deter animal access. Add climbing guards on poles, animal-resistant covers on transformers and potentially burying sections of line where necessary.
Falling objects	Emphasize proper grounding and implement fall protection measures like safety nets, guardrails, or personal fall arrest systems.

6. Monitoring and Evaluation

6.1. Key Performance Indicators

- Circuit Repairs & Maintenance
    - Outage duration in minutes
    - Circuit health performance
    - Time required to repair circuit
- Budget Allocation
    - Funds spent on more critical vs. less critical circuits
    - Funds spent on training teams and performance of circuits after repairs
    - Projects completed within budget and over budget
    - Funds spent on repairs vs. replacements

- Customer Experience
    - Internal team response time
    - Complaint resolution time
    - Post-outage survey response
    - Number of customers compared to previous years
    - Amount of customers affected for each outage

6.2. Data Collection Methods & Responsible Parties

- For problematic circuits, a weekly report with KPI statuses, improvements and concerns will be submitted by the field lead to the Business Analytics team and will be an aggregation of reports from field team members.

- For less problematic and non-critical circuits, a monthly report is generated with the same content and submitted by the field lead to the Business Analytics team for analysis.

- Performance reports of itinerant teams will be provided by the team lead after every project and submitted to the Project Management team for analysis.

LIMITATIONS AND FUTURE WORK

1. Limitations

Although our team was able to create a comprehensive report using information provided by IBEC, we also had to conduct extensive research through external sources to generate meaningful results. This is due to quite a few limitations that are elaborated below.

- Low Resolution Data
  - Despite there being about 100 rows of data for the circuit outage dataset, some circuits only have one record collected. This makes it difficult to analyze and find patterns because even when creating visualizations, we are not able to see the performance of the circuit with other conditions as there is only one instance.

- Insufficient Data for Trend Predictions
  - Since we would like to provide insight into patterns with circuit outages, we put IBEC's circuit performance data into three different machine learning models to analyze the results: logistic regression, decision tree, and neural network.
  - Out of these three, the logistic regression model performed the "best" as measured by accuracy, however we highly suspect this is also due to overfitting of the data.
    - When there is too little data present, the model learns to deal with only the situations it has been given rather than being able to analyze larger patterns.
    - It will be able to produce great results at this stage since the data comes from the same small dataset, but when given new data, it will struggle to provide accurate results.
  - After the logistic regression model, the neural network performed the next highest on the list, and was able to analyze trends despite the small dataset, but once again, we suspect that the problem of overfitting is prevalent.
  - Finally, the decision tree scored last but its accuracy was still over 50%, which means it is able to interact well with the data, but cannot yet provide accurate enough results for us to be able to use in circuit analysis.

- We are only provided data for one year, 2024, and very little data on 2023. This makes it close to impossible to analyze trends over the years, and implement a time based trend analysis for the months of the year as well.

2. Future Work

In the future, IBEC would greatly benefit from keeping a more dense record of circuit outages with deeper layers of information regarding each circuit. This would include its structure, specific components, information about the surrounding area, and even history of repairs and performance of the circuit for the past few years. With more data, not only would we be able to make more insightful analyses, but we would also be able to use this information in a machine learning model to decide where a new circuit should be located. A machine learning model that is properly trained with sufficient samples can predict the duration of an outage based on its location, cause, and time of year, all of which can be used to determine whether a circuit would perform well in a certain region.

Moreover, if there was more room in the budget, the next ideal step would be to upgrade infrastructure for more intensive monitoring services that would collect in depth data about each circuit and more specifically, what happens to the circuit internally when an outage occurs. The next place a higher budget would be allocated is to buy high quality equipment for upgrades, especially for underground circuits that experience the most amount of outages that affect a significant amount of customers.

In essence, IBEC should continue keeping records of their outages, but also incorporate more details that can be used for analysis. Should their budget increase in the future, the best place they can invest their money in is into buying high quality components for their circuits to enhance them further once our recommended steps for improvement have already been implemented.

CONCLUSION

Our analysis presents a clear, data-backed roadmap to reduce Customer Minutes of Interruption (CMI) and enhance service reliability across IBEC's Southern California network. Through statistical rigor, we have identified the circuits and regions most critical to customer experience and operational efficiency.

Our strategy places customer impact at the forefront–prioritizing upgrades where the largest number of customers are affected, and where outages are both frequent and long-lasting based on the CMI. From targeted equipment repairs in the Northern and Coastal regions, to preventative strategies in Mountain and Desert areas, our plan offers actionable steps that balance cost, infrastructure constraints, and customer satisfaction.

Through thoughtful analysis, tailored regional recommendations, and a scalable implementation plan, IBEC is now equipped to make smarter upgrade decisions, justify investments to regulators, and build trust with its customers. This proposal not only solves today's challenges but sets a strong foundation for smart, more resilient electrical service in the years ahead.

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