Pacific Gas and Electric Company

EPIC Final Report

Program	***Electric Business Technology***
Project	***EPIC 1 Project 08 – Distribution System Safety and Reliability through New Data Analytics Techniques***
Line of Business or Department	*Electric Operations*
Date	December 1, 2015
Version Type	*Final*

Table of Contents

1.0 Executive Summary

As part of PG&E's Electric Program Investment Charge (EPIC) program, PG&E pursued a demonstration Proof-of-Concept (POC) project aimed to explore how to leverage new data analytic techniques to improve distribution system safety and reliability. The objective of the demonstration was to demonstrate a visualization and decision support system to support PG&E's risk management efforts to enhance public and system safety as well as improve asset management strategies and investment plans for Electric Operations (EO). The project name is Distribution System Safety and Reliability through New Data Analytics Techniques, the software application demonstrated was the System Tool for Asset Risk (STAR).

The concept of STAR is to integrate electrical asset and system data from multiple sources to calculate individual asset and system risk scores based on severity of risk and probability of occurrence. The data can include asset attributes (age, material type, etc.) asset condition, geography, outage information and other relevant information. A user interface allows employees to review results in a geographical, tabular and graphical format. Figure 1, at the end of this executive summary, illustrates the basic concepts of the STAR application.

The STAR POC focused on four distribution asset classes (substation transformers, substation breakers, distribution primary overhead conductors and distribution wood poles) for risk score calculations. Additional asset classes were included as necessary to model complete circuits or for visual purposes. Along with risk score calculations and the ability to visualize those in multiple formats, other functionality included performing basic what-if analysis, algorithm maintenance, user defined queries, asset aggregation ability (e.g. substation, protective zone) and exporting results. For the purpose of the POC, STAR ingested data in a flat-file format from the various systems (i.e., the POC did not interface directly with source systems such as SAP and GIS, a fully functional STAR application will obtain the necessary data directly from source systems).

Key stakeholders from the asset management organization were engaged in the POC effort. The POC leveraged PG&E's risk management framework to develop risk score algorithms. This ability to focus on higher risk assets should provide insight for identifying work that has the greatest likelihood of improving public safety. While the POC was not used for investment planning purposes it provides the platform to demonstrate potential reduction in costs and improvement in customer reliability through the calculation and visualization of asset and system risk. The information in a production version of STAR would then be able to be used by asset strategists to better inform asset strategies and investment planning.

The evaluation results of the POC were compiled based on the feedback from PG&E personnel. The users participated through multiple demonstrations, training, user acceptance testing (UAT) and ongoing informal testing. User feedback was captured in three evaluation criteria categories: software quality, implementation ability and product usability. Additionally, STAR improvements and challenges relevant for future implementations were documented throughout the POC.

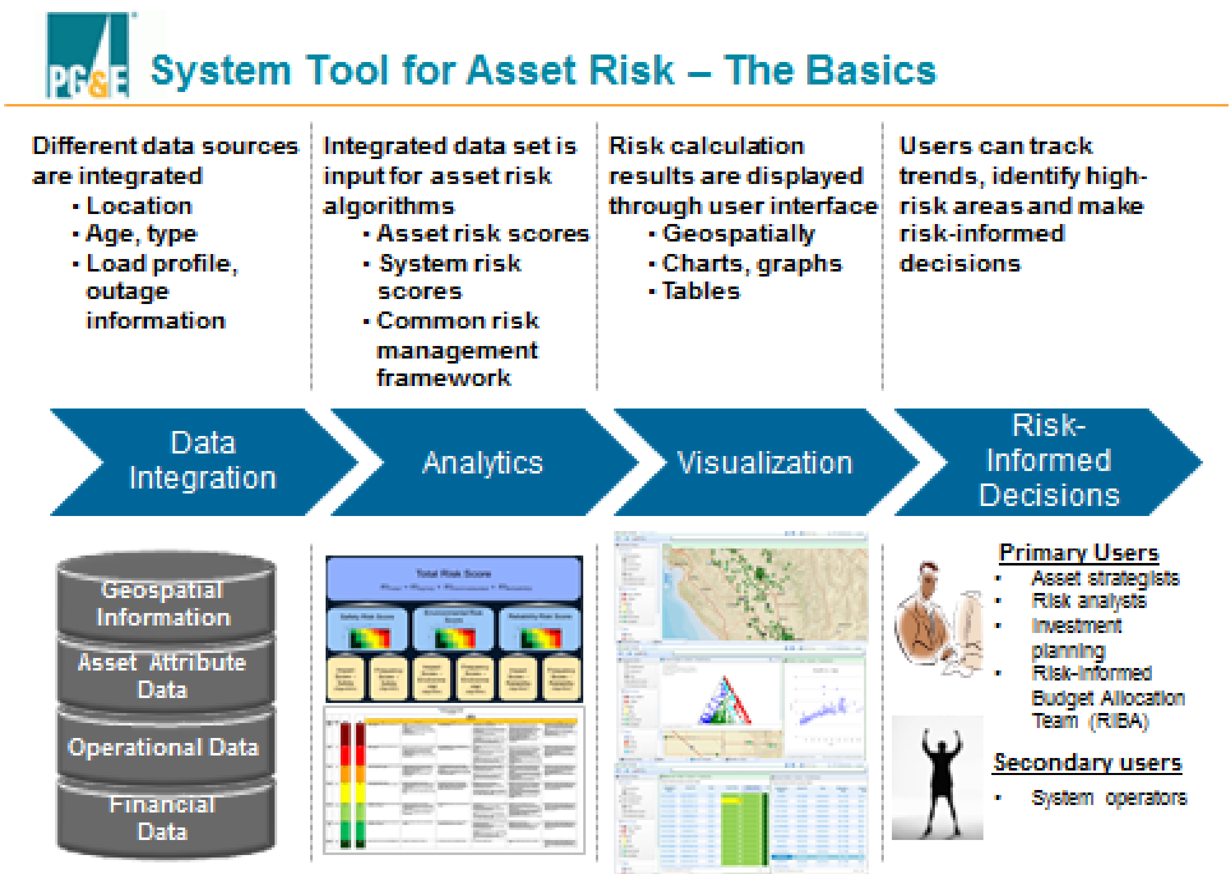
The success of the POC came in several overarching dimensions which will be expanded on throughout this report. The core successes of the POC are as follows:

- Increased understanding of market landscape
- Risk algorithm refinement and development
- Integration of geospatial information into the risk algorithms
- Understanding utility systems and data capabilities/issues

- Exposure of risk analysis technology and thinking to asset strategists and key utility personnel
- Developing robust implementation strategy

The outcome of this EPIC project was a POC demonstration that allows users to visualize asset risk calculations based on an integrated data set from different sources. Some issues were experienced relating to system performance, dashboard visualization and user interface errors, however those were characteristic of a proof of concept approach and PG&E believes the POC demonstrated capabilities which evidence the business value of a production system where these concerns can be addressed. The concepts here in the POC will have general applicability to not only California utilities but also the industry at large as it provides a demonstration of how ever-increasing amounts of data can be mined and combined for targeted, cost-effective use for system asset risk management leading to improved distribution system safety and reliability.

Figure 1. STAR Basics



2.0 Introduction

On November 1, 2012, in A.12-11-003, PG&E filed its first triennial Electric Program Investment Charge (EPIC) Application at the CPUC, requesting $49,328,000 including funding for 26 Technology Demonstration and Deployment Projects. On November 14, 2013, in D.13-11-025, the CPUC approved PG&E's EPIC plan, including $49,328,000 for this program category. Pursuant to PG&E's approved EPIC triennial plan, PG&E initiated, planned and implemented the following project: EPIC1.08 Distribution System Safety and Reliability through New Data Analytics Techniques, also known as the System Tool for Asset Risk (STAR). Through the annual reporting process, PG&E kept CPUC staff and stakeholders informed on the progress of the project. The following is PG&E's final report on this project.

3.0 Problem Being Addressed

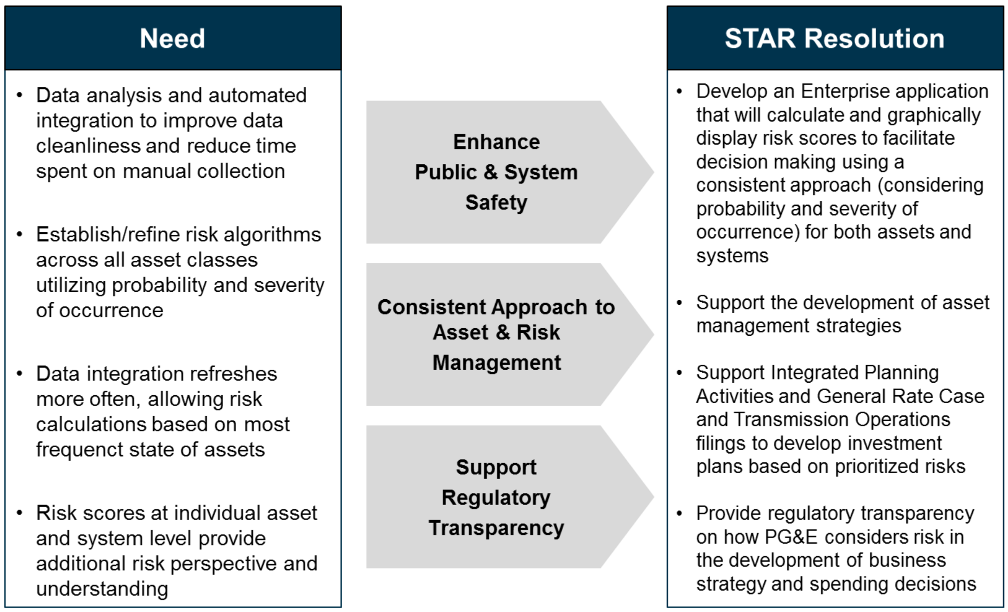
PG&E is implementing a risk management framework to enhance public and system safety. In order to foster a consistent approach and provide transparency in the regulatory process it is appropriate to investigate how technology can automate and support the effort. PG&E currently analyzes risk for a subset of assets utilizing a subset of data across multiple systems. These analyses leverage one off spreadsheets and calculation methodologies and require manual collection and consolidation of data. These current processes are time consuming, manually-intensive, and disruptive to ongoing operations. At the same time, the amount of data inside the utility continues to grow exponentially. A standardized approach to asset and system risk scores for a larger number of asset classes and systems that are enabled by technology for faster more thorough analytics will enable the continued development of this risk management framework.

PG&E wants to leverage additional internal and external data sources to continue to refine the risk algorithms for a variety of asset classes. PG&E risk algorithms will continue to evolve with the ability to ingest operational data and geospatial information such as population density and wind and snow loading maps. The ability to geospatially visualize asset and systems throughout the service territory and the interaction between geospatial information and the risk algorithms enables asset strategists to make confident and consistent decisions. Using all data appropriate and available to calculate asset and system risk scores will also help develop robust risk calculations.

The automated integration of data across disparate source systems will reduce the time spent collecting and consolidating data across PG&E. Manual manipulation of data and formulas in spreadsheets are prone to errors and inconsistent results. An application that integrates the necessary data and uses it in PG&E standard risk algorithms reduces the likelihood of errors and promotes consistent decisions. Ultimately, the STAR demonstration POC proved the concept of applying multiple data sources and risk scoring to enhance effective risk management for a subset of electric distribution, substation and line assets for a portion of PG&E's service territory.

Figure 2 below summarizes the issues/needs and how technology can provide a resolution.

Figure 2
Needs & Resolutions



3.1 Overview

PG&E is pursuing a risk-based asset management strategy to enhance public and system safety. As part of this pursuit, PG&E created the proof of concept system called STAR as an EPIC initiative to demonstrate and study an information system that calculates asset and system risk scores based on severity of risk and probability of occurrence. This project was ideal for the EPIC program since there are few vendors in this space, and the ability to leverage “big data” for better asset management in utilities is a new technology that has not been proven / implemented in large scale. The asset risk scores created through the program’s algorithms can be used to inform asset management strategies, investment plans and ad-hoc analysis. This type of system is not only new to PG&E, but also to the utility industry.

The STAR POC:

- Calculates asset health indices and risk scores
- Represents the risk scores geospatially and graphically
- Facilitates risk analysis at an asset and system level

3.2 POC Scope

To demonstrate the feasibility and usefulness of STAR as well as its potential benefits, PG&E decided to move forward with a POC. A set of requirements was created and a request for proposals (RFP) was issued in March, 2014. Multiple vendors submitted proposals and a selection was made to create a POC.

Requirements originating from relevant business processes were used to establish STAR functionality for the four asset classes in scope. From August 2014 to February 2015, the software vendor worked with PG&E personnel to build a risk analysis tool for users to evaluate areas such as user-interface experience, advanced analytic capabilities, data management and technical specifications (e.g. scalability, integration, etc.). Below is a high-level outline of the prototype requirements:

Schedule

- POC development ran from August 2014 until February 2015
- POC evaluation ran from February 2015 until April 2015
- Report preparation ran from April 2015 to September 2015

Functionality

- Calculate and display risk scores using PG&E defined algorithms at both an individual and aggregate asset level (substation, circuit, sub-circuit, or asset-type)
- Ability to perform low level of "what-if" analysis (e.g., weighting risk factors)
- Demonstrate how algorithms can be modified for "what-if" analysis (using R language)
- Able to prepare some user defined reports/queries and export results

User Interface

- The POC user interface was representative (but not necessarily a final version) of what the STAR production tool will look like.
  - Asset selection by type and "system" (substation, circuit, protection zone, all poles, etc.)
  - Display results both geospatially and graphically (e.g., assets coloured by risk score), in tables and via multiple visual formats (bar graphs, scatter charts, etc.)
  - Show how risk scores change based on asset selection
  - Export tabular data (i.e., into excel, etc.)

Geographic & Asset Scale

- The POC included assets from the Central Valley region where PG&E has implemented its new EDGIS system.
- The POC included four asset types:
  - Distribution poles
  - Primary overhead conductor
  - Distribution substation transformers
  - Distribution breakers
- Additional assets were included for visualization purposes only.

Architecture

- The POC was hosted in an environment offsite and utilized cloud services to access the application.

Data Sources

- A flat file approach was utilized to load data from multiple sources into the STAR database. More detail is available in the data sources section below.

3.3 Source Data

The value of a future production version of STAR will be commensurate with the level of integration between STAR and core enterprise data systems, as well as the ability of STAR to link risk outputs between these systems geospatially and in dashboards (tables, charts, dials). To minimize the level of complexity required for a fully integrated STAR solution, a flat file approach was utilized for the POC. Various exports from the source databases were ingested into the STAR POC instead of an integrated enterprise architecture that will be necessary for a STAR production system.

PG&E evaluated and determined the source data systems that would be utilized in the STAR POC.

<u>STAR POC Data Sources:</u>

- Electric Distribution Geographic Information System (EDGIS)
- ERP (Financials, Supply Chain, Work & Asset Management)
- Outage Database (outages, customer interruptions, customer minutes)
- Aspen Oneliner (transmission fault duty)
- CYME (Distribution load flow)
- Splice Dataset (field collected information on in-line primary splices)
- Delta X (Substation equipment condition information)
- Offline Datasets (Excel)

The STAR POC scope included four asset types that were used for visualization, analysis and validation. Those assets were:

- Distribution Poles
- Distribution Overhead Primary Conductors
- Distribution Substation Transformers
- Distribution Breakers

Table 1 below shows the relationship between data source systems and the prototype assets.

Table 1
STAR POC Source Systems

	Source Systems							
	Electric Distribution Geographic Information System (EDGIS)	ERP (Financials, Supply Chain, Work & Asset Management)	Outage Database	Aspen Oneliner	CYME	Splice Inventory	Delta X	Offline Databases (Excel)
Poles	✓	✓	✓	✗	✗	✗	✗	✗
Conductors	✓	✓	✓	✗	✓	✓	✗	✓
Distribution Sub Transformers	✓	✓	✓	✓	✗	✗	✓	✓
Distribution Sub Breakers	✓	✓	✓	✗	✗	✗	✓	✓

Table 2 provides an approximate number of core assets that were available for analysis in the POC. Additional asset details, including attributes, can be found in the appendix.

Table 2
Asset Counts

Asset Type	Count
Distribution Wood Poles	591,237
Distribution Overhead Primary Conductor (Line Sections)	423,392
Distribution Substation Transformers	290
Distribution Breakers	1949

Additional assets and information were included for visualization purposes to represent a complete distribution circuit:

- Distribution Underground Primary Conductors
- Distribution Overhead Protective Devices (i.e. Reclosers, Fuses, Sectionalizers, Interrupters)
- Distribution Overhead Line Switches
- Distribution Overhead Line Transformers
- Substation Locations
- Substation Single Line Diagrams

The most significant data source for STAR is PG&E's GIS. The company is currently implementing an updated EDGIS. During the data ingestion of the STAR POC, the new EDGIS was only available in the Central Valley Region (this region includes the area from approximately Bakersfield to Stockton in the San Joaquin Valley of California). Consequently, the POC only used data from that area.

3.3.1 Data Access

Upon request, PG&E will provide access to data collected that is consistent with the CPUC's data access requirements for EPIC data and results.

3.4 Data Quality

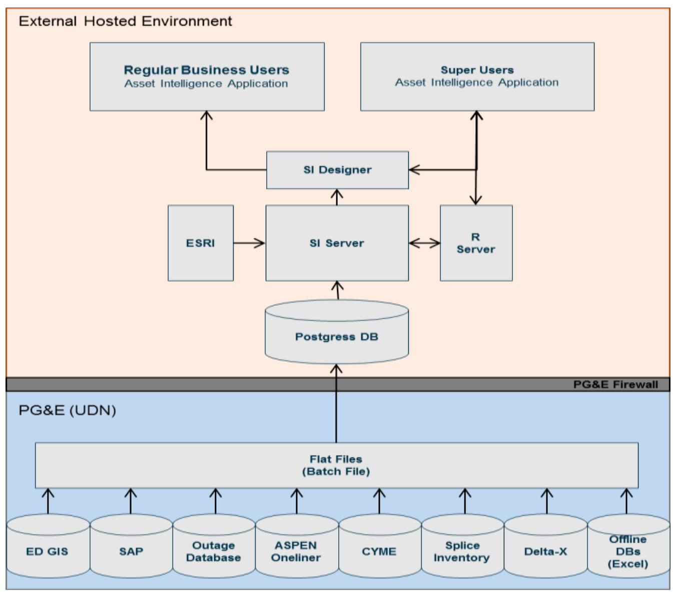
The effectiveness of STAR depends on the accuracy and completeness of the utilities data. It is important to fully understand source data quality and availability. PG&E is aware of source data challenges and the potential effect they can have on a STAR production system. One of the results of the POC is further insight into specific data concerns. Source datasets were vetted to provide insight into the POC data capabilities and issues were documented for a greater understanding of future challenges. STAR provides a framework for better understanding data requirements as they relate to asset risk.

Another learning from the POC to address data quality issues was the concept of applying confidence factors to risk scores.This approach will help users understand the robustness of the asset and system risk scores. High, medium and low confidence factors were established by determining the completeness of the source data used in the calculations. Risk scores with high confidence factors indicate a more robust risk score relative to those with a low confidence factor. Low confidence factors will indicate to users that additional analysis may be required. Moving forward there will be an effort to improve on the confidence factor and review options for reporting data issues back to source systems to assist with data enhancement activities.

3.5 Architecture

To simplify the data migration process, it was decided to perform a data extract out of the PG&E systems and load that data to the POC environment database. It is recognized that this approach is not relevant for a production system solution but provides sufficient information for a demonstration POC evaluation. A STAR production system solution will require enterprise system integration and a periodic data exchange between environments, which will require deeper, more costly IT integration. The following diagram is the high level data architecture utilized for the STAR POC.

Figure 3
STAR POC Architecture



3.6 PG&E Enterprise Operational Risk Management Program

To support the timely creation of the risk algorithms for the STAR POC, the project used components of the PG&E Enterprise Operations Risk Management (EORM) framework process as a starting point in the development of the STAR asset risk algorithms. The STAR POC algorithms were not used to make any investment portfolio decisions. Rather the algorithms provided a means to evaluate the capabilities of the vendor application and continue refining asset and system risk models.

The EORM program developed the use of a Risk Evaluation Tool (RET) which facilitates comparison of risks both within lines of business, and across lines of business. The risk evaluation tool employs a 7 x 7 matrix (see Figure 4) where potential impacts of the risk scenario are scored across six impact categories and one frequency category. The impact categories are: Safety, Environmental, Compliance, Reliability, Trust and Financial. Once the impact and frequency scores are articulated, the algorithm is applied to calculate a risk score[1].

Figure 4
RET 7 x 7 Matrix

Frequency Description	Frequency per Year	Frequency Level	Impact Level
> 10 times per year	F = > 10	Common (7)	Catastrophic (7)
1 - 10 times per year	F = 1 - 10	Regular (6)	Severe (6)
Once every 1 - 3 years	F = 1 - 0.3	Frequent (5)	Extensive (5)
Once every 3 - 10 years	F = 0.3 - 0.1	Occasional (4)	Major (4)
Once every 10 - 30 years	F = 0.1 - 0.033	Infrequent (3)	Moderate (3)
Once every 30 - 100 years	F = 0.033 - 0.01	Rare (2)	Minor (2)
Once every 100+ years	F = < 0.01	Remote (1)	Negligible (1)

Impact Categories:

- Safety
- Environmental
- Compliance
- Reliability
- Trust
- Financial

In addition to the RET, PG&E employs a Risk Informed Budget Allocation (RIBA) process to inform the prioritization of budget for risk mitigation measures and other work in its portfolio. RIBA scores are calculated for projects in an excel model. The RIBA process scores projects along three of the six RET impact categories: Safety, Environmental, Reliability and three frequency scores (one for each impact dimension).

Similar to the RIBA process, the STAR POC risk algorithms are calculated based on three impact dimensions: Safety, Reliability and Environmental. A frequency and impact score is determined for each impact category, these frequency and impact scores are inputs into a risk score equation which determines the individual risk score for each category. The total risk score for each asset is the summation of the individual risk scores for each asset. A detailed risk calculation walkthrough for the four asset classes is provided in the appendix.

[1] For more information please refer to PG&E's testimony in the Safety Model Assessment Proceeding (A. 15.05.003).

4.0 STAR POC Results

4.1 Evaluation Process

Upon completion of the STAR POC project, an evaluation phase commenced. The purpose of the evaluation was to understand the POC results in order to apply the knowledge gained to a possible future production system. To gain a comprehensive understanding of the POC success, it was necessary that each user's experience with the product be understood. There were 13 users that interacted with the POC through the following activities:

- Sprint demos (4)
- Ongoing informal software testing
- User Acceptance Testing (UAT)

Individual documented results from the UAT (unexpected & desired results) as well as user interviews based on experience with the product throughout the POC provided important details for the evaluation. An evaluation criteria worksheet along with a supporting PowerPoint deck was used to capture the feedback.

4.2 Evaluation Criteria

The evaluation criteria worksheet established 19 criteria (see below) grouped into three categories: (1) Software Quality (2) Implementation Ability and (3) Product Usability. Input from both business and IT users provided details for the PG&E experience with the STAR POC. Based on the results, potential mitigations were identified for both the POC and a potential production version of STAR.

Software Quality Criteria

- Performance
- Reliability
- Visualization
- Analytics (Algorithms)
- Maintainability
- Interoperability
- Functionality

Implementation Ability Criteria

- Customize Functionality
- Customize Usability
- Ingesting Source Data
- Timeliness
- Project Management
- Communication
- Meet Requirements
- Training

4.3 Evaluation Results

The evaluation in the areas of software quality, implementation ability and product usability provide mixed results. There were positives in the ability to quickly stand up an application to visualize asset risk and flexibility with compiling data and calculating results. The POC application provided an imperative tool for communicating the future vision and refining business processes and functional requirements. Negative feedback included slow initial system performance due to the POC being hosted in a cloud environment, as well as an abbreviated process for refining and optimizing how data is accessed (e.g., what data elements are retrieved and at what time in the workflow) both of which are attributable to the nature of creating a POC. Overall, the POC provided users with a significant amount of knowledge in the potential of STAR and will be able to apply many lessons learned going forward.

4.3.1 Software Quality

The quality of the software product was evaluated using several criteria (see appendix for additional details). The software quality evaluation focused on the base product used for the POC and its alignment with user expectations in several areas.

When reviewing performance and system reliability issues, it should be noted that architecture of the POC differs greatly from the expected architecture of a production system. Differences include cloud based access with a 3rd party responsible for system maintenance vs. the complete system architecture internally housed and maintained by PG&E. Also, the typical effort in system optimization and periodic performance tests was not applied during this project. Finally, while the POC used flat files, the STAR production system solution will require enterprise system integration.

Aspects of the software that met user expectations included visual risk score results on the map and in tables, asset information available to the user, R programming language functionality for algorithm maintenance and the ability to integrate several source datasets for risk analysis. Users were able to effectively navigate the geographic view with panning and zooming tools as well as establish favorites to keep user settings. Tables provided detailed asset information and color coded risk scores that users could create subsets of using querying functions. Also, the vendor was able to quickly stand up an application for some initial asset visualization.

Overall, the users expect an increase in performance from the POC to a production quality system. Users dealt with some performance issues concerning delays with table querying and sorting processes as well as map rendering. Occasionally, application and/or computer restarts and clearing browser caches were required to continue with testing efforts. Application errors and bugs caused different results when performing the same task. Map, table and chart visualization issues were reported regarding symbology and navigation. These results proved that (1) users are engaged in the tool and (2) feedback is crucial to align stakeholder expectations. Despite these observations, there were many lessons learned that will be applied to the solution going forward. PG&E can leverage the POC and the associated findings to better define use cases and user requirements for a production version.

It is worth reiterating that the demonstration POC process moved quickly from concept to product. Due to the nature of a POC, less time was spent in assessment, design and testing activities. This approach resulted in some of the user experiences described above.

4.3.2 Implementation Ability

The implementation of the software product by the vendor was evaluated using several criteria (see appendix for additional details). The evaluation of the implementation ability focused on the outcome of activities necessary for this type of a software implementation.

The vendor worked with PG&E to successfully establish requirements and user stories in an online system that allowed progress to be tracked as well as feedback and bug reporting from the end users. A design document that captured user interfaces, configuration and data migration specifications was created during initial project workshops with PG&E. As PG&E became more aware of product capability and POC needs, additional scope was added to the project. This included demonstrations about how the application accesses substation one-line diagrams (from both EDGIS and engineering drawings) and the implementation of Duval Triangles (which display the results of dissolved gas analysis tests).

The implementation of the STAR POC posed many challenges. Functional requirements mandated that some customization was necessary to meet the POC expectations. It also became evident as the project moved forward that the lack of a system integrator during the POC resulted in some implementation issues. With an agile project management process in place, tasks regarding communication, issue/risk management and schedules were not managed as well as anticipated. Issues reported by users involving processes and intuitiveness of the product can be associated with ineffective communication. Also some issues related to creating the electric distribution circuitry in STAR (i.e., the connectivity model) led to delays which were mitigated in part by the vendor adding additional specialized resources to the project. A key learning from the POC is that the system integrator role is important to maintain project implementation success.

4.3.3 Product Usability

The usability of the product was evaluated using several criteria (see appendix for additional details). The product usability evaluation focused on the intuitiveness of the POC and the alignment with user business processes and relevant risk analysis processes. The scope of the POC did not include consideration regarding the production version of the application in areas of RIBA, EORM or any other relevant activities.

The general feedback was mixed; the users felt that the amount of "mouse clicks" exceeded what they expected for risk assessment exercises. During testing, it became evident that the product didn't fully provide relevant PG&E work processes to the extent expected for the POC. However, the feedback on product usability was invaluable because it facilitated the discussion between product developers and stakeholders and led to refinements in business requirements. The product documentation was thorough and useful to the user for "OTB" functionality when accessed. There was a supplemental training guide that provided additional documentation on functionality specific to this POC.

Many of the issues related to product usability are directly related to the implementation activities. A condensed design phase, lack of a system integrator, and minimal user interaction during certain software development activities contributed to a product that did not meet all usability expectations. However, PG&E is confident that with the proper project management staffing, a thorough plan/analyze phase that builds on the lessons learned from the POC and increased user involvement; it is possible to create a production version of STAR that aligns with the user's expectations.

5.0 POC Benefits

5.1 Benefits and Lessons Learned from the POC

The STAR POC yielded the following benefits and lessons learned.

- **Market Landscape:** The POC vendor selection process provided PG&E insight regarding the capabilities of technology firms in the areas of data integration, analysis and visualization for the purpose of using risk analysis in electric utility asset management. At the time of awarding the POC, PG&E concluded that only two of the 12 firms responding to the RFP could deliver a viable POC per the specified schedule and requirements. This indicated to PG&E that firms engaged in this field were limited, re-inforcing that this project was ideal for an EPIC demonstration. Since awarding the POC, PG&E has continued to engage with the analytics, visualization, and situational intelligence market. This has included engagements with other firms for analytic big data projects that pursue different outcomes, such as real-time situational intelligence. PG&E believes the number of vendors capable of providing the necessary solution has continued to increase since 2014 but the market is still maturing.
- **Algorithm Development:** Creating a POC required PG&E to consider how current algorithms (and decision processes) used to inform asset replacement decisions can be adapted to the STAR POC and how a production version of the application can provide a framework to further develop those algorithms. The STAR POC also facilitated the identification of the required analytics skillset. Through the POC, PG&E identified key functional areas needing strengthening in order to ensure full utilization of a STAR production system. These functional areas include data science, statistical analysis and machine learning.
- **Integration of Geospatial Information in the Risk Algorithms:** By ingesting geospatial overlays in the STAR POC such as population density, wind and fire maps, PG&E is able to take a step towards incorporating more advanced geospatial information in the risk calculations.
- **Understanding System and Data Capabilities/Issues:** Deciding on the scope for the POC required PG&E to consider the relationships between disparate systems as well as the quality of the data in those systems. For STAR to be effective in a production system, all source datasets will need to be integrated in an automated data sharing system. By better understanding the data quality of the source datasets, PG&E can determine the appropriate phased approach to establishing a production STAR. PG&E can feel more confident in pursuing risk functionality for assets where the data is more reliable for an initial production phase and establish a strategy to improve relevant asset data for subsequent phases.
- **Exposure of Risk Analysis Technology and Thinking to Asset Strategists:** Utility should have a strong foothold in risk analysis methodologies and how they should be applied to asset and system risk scores. The process of creating an interactive POC provides personnel first-hand knowledge of how that technology applies to improving asset risk algorithms and aligns with business processes. This knowledge will be important when applied to future assess and design activities of a production STAR.
- **Developing a Robust Implementation Strategy:** Learnings from the POC allowed PG&E to start to develop a potential implementation strategy for a production system including understanding the necessary resources required both internally and externally necessary for a successful production implementation. The POC also allowed PG&E to determine if a production system would provide business value and what kind of staged approach would lead to the best results. Detailed analysis and design phases are needed to understand all potential data issues.

6.0 Future of STAR

A production version of the STAR tool is envisioned to be the source system for asset and system risk scores for transmission and distribution (T&D) facilities that: (1) asset management will utilize when developing asset strategies; and (2) will provide insight to regulatory agencies about how PG&E explicitly considers risk in the development of business strategy and planning decisions. STAR primary users will be Asset Managers and Risk & Compliance teams to support integrated planning activities and ad-hoc analysis.

6.1 Algorithm Improvements from POC to Product

The work done throughout the POC led to important lessons learned for the future of STAR asset and system risk algorithms. As more data is integrated and data science capabilities are strengthened at PG&E, the asset and system risk scores will continue to develop. PG&E has recently established a data scientist track to ensure the internal capabilities are established and maintained. These data scientists will be tasked with using statistical software tools, such as R, to build and refine predictive models for appropriate asset classes. These indivdiuals will enable a more advanced understanding of the probability of failure of assets in PG&E's system while the integration of additional external and internal geospatial data sets will enable more complete consequence of failure calculations. The combination of building advanced analytical capabilities and continuing to leverage PG&E's enterprise risk framework will facilitate a standardized risk model at PG&E which will allow consistent decision making across the organization.

6.2 Benefits Expected with Production System

The benefits expected with the implementation of a STAR production system include:

Table 3
Production System Potential Benefits

Benefit Area	Benefit
Quality of Service	• Improve public safety by identifying and addressing higher risk assets • Reduce in unplanned outages amd customer interruptions • Improve SAIFI / SAIDI
Planning	• Replacement of equipment at non-premium costs due to replacing before failure • Turn unplanned replacements into planned replacements • Avoid unneeded replacements as a result of better information • Increase in productivity due to accelerated analysis/conclusions and increase in transparency and confidence of data • Gain hours or reallocation of hours to do better analysis • Improve ability to scope projects and bundle work • Improve risk informed Capex spending, planning and processes • Alignment with existing risk based processes • Define "effective age" of assets which supports more accurate prediction of future performance of assets and asset classes
Operations	• O&M condition based maintenance using risk information

Other	• Improvement in rate case showings through enhanced risk informed decision making • Increased efficiency in preparing rate cases and responding to data requests. • Increased efficiency in preparing data for internal/external requests/audits/initiatives (risk requests may increase) • Improve communication with stakeholders regarding assets and risks - community, regulatory, public • Improve enterprise collaboration, apply best practices and governance.

The proposed STAR production system will be integrated with other systems to build a platform that will provide asset managers and other users the ability to more effectively evaluate safety, regulatory compliance, and reliability based on the condition of the aging infrastructure and builds the strategy based on priority.

- Economic Benefits
  - Maintain/Reduce operations and maintenance costs
  - Maintain/Reduce capital costs
  - Number of operations of various existing equipment types (such as voltage regulation) before and after adoption of a new smart grid component, as an indicator of possible equipment life extensions from reduced wear and tear

- Safety, Power Quality and Reliability (Equipment, Electricity System)
  - Outage number, frequency and duration reductions
  - Public safety improvement and hazard exposure reduction
  - Utility worker safety improvement and hazard exposure reduction

- Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy
  - Dynamic optimization of grid operations and resources, including appropriate consideration for asset management and utilization of related grid operations and resources, with cost-effective full cyber security (PT Code 8360)*
    - STAR also establishes a standardized system where industry best practices and algorithms can be shared within the utility community.

- Adoption of EPIC technology, strategy and research data/results by others
  - EPIC project results referenced in regulatory proceedings and policy reports

6.3 Plans for Deployment

- STAR Plan/Analyze Phase – Determine the functionality, user-interface, architecture and other requirements for a full STAR production system.
- STAR Phase 1 – Implement the functionality defined during the plan/analyze phase for TBD Transmission and Distribution asset classes
- STAR Phase 2 (and beyond): Implement the STAR tool for other electric Transmission and Distribution system assets. Also refine and upgrade functionality as appropriate.

STAR will enable PG&E to manage risk in a transparent manner through consistent application of risk formulae, as well as supporting the creation of asset projects, linking projects to the risk elements associated with assets. It is envisioned that STAR has the potential to leverage financial data as it relates to maintaining or replacing assets, linking analysis of asset investment to asset survival rates. Some of this functionality will be sought in the near term, with the rest considered at a later time. A future STAR production solution would be developed using General Rate Case (GRC) funding.

7.0 Appendix

7.1 Data Source details

The table provides system names, descriptions, version during POC and format of the data extraction.

Table 4
Data Source Details

System	Description	App/DB Versions	Data Extract File Format
Electric Distribution Geographic Information System (ED GIS)	Distribution Geospatial system including network connectivity model	ESRI 10.1 Oracle Spatial	Database export: Oracle 11g Geospatial attributes: Native ArcGIS, or Oracle SDO
Land Base Geographic Information System (LB GIS)	Land Base Geospatial System	ESRI 10.1 Oracle Spatial	Shape file
ERP (Financials, Supply Chain, Work and Asset Management)	SAP Enterprise wide asset management, work management with integrated financials and supply chain system.	SAP ECC6 Oracle 10g	Delimited flat file/s (pipe or .csv)
Outage Database	Repository for outage information such as customer minutes, customer interruptions, number of sustained outages, etc.	Note: CEDSA migrating to ED GIS and Outage Database Re-Write Ventyx FocalPoint 6.6.5 Oracle 11g	Excel file

System	Description	App/DB Versions	Data Extract File Format
ASPEN Oneliner	Transformer replacement list and bus fault duty.	Oneliner 11 Oracle 10	Excel file
CYME	Distribution lines and ratings	CYMDIST 7.1 r2 Oracle 10g	Access database
Splices	Inventory of Primary Overhead Conductor splice locations.	Excel	Excel file
Delta-X	Substation and transformer conditions from DGA analysis and oil quality	Excel	Excel file
BRKR-D Replacement List	Source of SAP Equipment ID	Excel	Excel file
Central Valley Region Substations and Feeders	In scope substations	Excel	Excel file
High Failure Rate Make and Model	High failure risk for make and model combination	Excel	Excel file
TXFR-D Replacement List	Source of SAP Equipment ID	Excel	Excel file

7.2 POC Evaluation Criteria

The POC Evaluation Criteria table provides the list of criteria and their description used for the STAR POC evaluation. The criteria are categorized as Company, Software Quality, Implementation Ability or Product Usability.

Table 5
POC Evaluation Criteria

Criteria	Description
Software Quality	
Performance	How does the performance of the software seen during the prototype compare with your expectations? If you're aware of other customer's performance experience; consider those. Perspectives include end user and IT.
Reliability	How reliable has the software been during the prototype as far as accessibility and errors? If you're aware of other customer's reliability experience; consider those.
Visualization	How is the user experience from an aesthetic point of view?
Analytics (algorithms)	Ability to ingest data, apply algorithms and display results for the purpose of risk analysis.
Maintainability	How easily do you think the software can be maintained when changes such as algorithms, work processes and source databases occur?
Interoperability	How easily does this software integrate with other systems? Consider all of the potential datasets such as GIS, SAP, Outage, Engineering, etc.
Functionality	Is the out of the box functionality along with customization capability there to meet your requirements?
Implementation Ability (Vendor Resources)	
Customize Functionality	How effective have the vendor resources been on customizing functionality in STAR?
Customize Usability	How effective have the vendor resources been on customizing the user experience in STAR?
Ingesting Source Data	How effective have the vendor resources been on integrating multiple datasets into STAR? Also includes the ability to bring in non PG&E data for risk analysis.
Timeliness	How well did the vendor team perform in regards the STAR schedule?
Project Management	Detail Agile PM effectiveness.
Communication	Explain the application, processes, interact with PG&E team.
Meet Requirements	Did the vendor meet the original functional requirements and craft the user stories to meet PG&E's needs for STAR?
Training	How well did the vendor conduct the user training? How effective was it?
Product Usability	
Understandability	Is the STAR application understandable and easy to navigate?
Translation of Business Processes	How effectively can this product produce productive business processes?
Documentation	How complete and usable is the STAR application documentation?
Learnability	How easily can users learn the application? Is it intuitive?

7.3 Algorithms

Core to the STAR tool is the handling of risk algorithms relating to both individual and aggregated assets within the Electric Operations line of business. The risk algorithms incorporate elements of both probability of failure and severity of failure. The STAR tool supports the risk calculation based on existing algorithms, but also facilitates testing and creation of new algorithms based on statistical analyses of data, as well as evolution of algorithms as new data sources become available.

7.3.1 Distribution Substation Transformer Risk Score Calculation

The following steps walk through risk score calculation for distribution substation transformers.

Figure 5
High Level Step-By-Step Risk Score Calculations for Distribution Substation Transformers

1 Calculate the 1-7 Safety, Reliability and Environmental Impact

2 Calculate the 1-7 frequency score

3 Calculate the $RS_{safety(S)}$, $RS_{environmental(E)}$ and $RS_{reliability(R)}$

$$RS_{S,E,R} = k^{[0.5\ \mathrm{Log}(f_{S,E,R}) + I_{S,E,R}]}$$

where: f = the number of occurrences expected over a one year time horizon
and I is the impact of the event
and k is the scalar and is a fixed number of 3.16227766017085
and 0.5 is the standard risk reduction factor for aggregating the impact of uncorrelated occurrences

And $f_{S,E,R} = \frac{1}{T_{S,E,R}}$ where

Frequency Score (RIBA)	T (# Years)
1	1000
2	100
3	30
4	10
4.5	5
5	3.33333
6	0.1
7	0.01

4 Calculate the Total Risk Score

$$RS_{Total} = RS_{Safety(S)} + RS_{Environmental(E)} + RS_{Reliability(R)}$$

The determination of the 1-7 Safety, Reliability and Environmental impact and frequency scores (steps 1, 2) is below:

<u>Reliability</u>: The impact dimension for reliability is determined based on the number of customers served by the individual substation transformer. The calculation for the reliability impact score is:

$$Reliability\ Impact\ Score\ (R_I) = LOG(\#Customers) + 1$$

The frequency dimension for reliability is determined based on a weighted average score of several asset attributes. Each attribute is scored based on a range from 0-20. The asset attributes and their individual weightings are as follows:

Table 6
Reliability Score Details

Attribute	Value	Weight (W_i)
Age	0-20 Score	25.8%
DGA/Oil Quality	0-20 Score	51.6%
Through Fault	0-20 Score	12.9%
Top 5 worst transformer in HQ	0-20 Score	9.7%

Each attribute score is determined as follows:

Age

Table 7
Transformer Age Range Values

Age Range	1 Phase Value	3 Phase Value
0 ≤ Age ≤ 5	1	1
6 ≤ Age ≤ 10	2	3
11 ≤ Age ≤ 15	3	5
16 ≤ Age ≤ 20	4	7
21 ≤ Age ≤ 25	6	10
26 ≤ Age ≤ 30	8	12
31 ≤ Age ≤ 35	10	14
36 ≤ Age ≤ 40	12	16
41 ≤ Age ≤ 45	14	18
46 ≤ Age ≤ 50	15	20
51 ≤ Age ≤ 55	16	20
56 ≤ Age ≤ 60	17	20
61 ≤ Age ≤ 65	18	20
66 ≤ Age ≤ 70	19	20
Age > 70	20	20

DGA/Oil Quality

Table 8
DGA/Oil Quality Values

DGA Score	Oil Score	Attribute Value (0-20)
1	1-2	0
1	3	5
1	4	10
2	1	0
2	2	3
2	3	5
2	4	10
3	1-3	15
3	4	20
4	1-4	20

Through-Fault

$$Through\ Fault\ Score = Min\left[\frac{Fault\ Duty_{Max}}{1000}, 20\right]$$

Top 5 worst transformer in HQ

Table 9
Worst Transformer Values

Top 5 Worst?	Attribute Value$_j$ (0-20)
No	0
Yes	20

Once the attribute score is calculated for each attribute, the overall health index for the reliability frequency score is determined as follows:

$$Health\ Index\ (HI) = \sum_{j=1}^{n} W_j * Attribute\ Value_j$$

Once the health index is calculated, the overall frequency dimension is determined based on a mapping from the health index score

Table 10
Health Index Score

Health Index (HI)	Frequency Score
HI > 16	7
14 ≤ HI < 16	6
10 ≤ HI < 14	5

7 ≤ HI < 10	4
HI < 7	3

Safety: All distribution substation transformers received a safety impact score of 1 and a safety frequency of 1.

The safety impact score of 1 was determined because: although the worst case scenario of a catastrophic failure of a substation transformer bank causing fatalities and injuries is a rare possibility, the worst reasonable direct impact of an injury/fatality during a catastrophic bank failure is low. Any scenario involving such a fatality most likely would involve the failure of a protection device which could not be mitigated by replacing the transformer

The safety frequency score of 1 was determined because: a) protection schemes are designed to de-energize the bank prior to failure; b) banks are occasionally forced out of service to avoid an in-service failure; and c) the likelihood of an employee or a 3rd party close enough to a bank during an event of this magnitude is rare.

Environmental: All distribution substation transformers received an environmental impact of 2 based on the possibility of a small, locally contained oil leak.

The environmental frequency score is determined based on the age of the transformer. It is determined that older transformers have a higher probability of an oil leak. The frequency score of transformers greater than 40 years old is a 4, and the frequency score of transformers equal to, or younger than 40 years old is a 3.

7.3.2 Distribution Substation Breaker Risk Score Calculation

The following steps walk through risk score calculation for distribution substation transformers.

Figure 6
High Level Step-By-Step Risk Score Calculations for Distribution Substation Breakers

1 Calculate the 1-7 Safety, Reliability and Environmental Impact

2 Calculate the Safety, Reliability and Environmental frequency scores

3 Calculate the $RS_{safety(S)}$, $RS_{environmental(E)}$ and $RS_{reliability(R)}$

$$RS_{S,E,R} = k^{[0.5\,\mathrm{Log}(f_{S,E,R})+I_{S,E,R}]}$$

where: f = the number of occurrences expected over a one year time horizon
and I is the impact of the event
and k is the scalar and is a fixed number of 3.16227766017085
and 0.5 is the standard risk reduction factor for aggregating the impact of uncorrelated occurrences

And $f_{S,E,}=\frac{1}{T_{S,E}}$ where

And $f_R = Adjusted\ Probability\ of\ Replacement$

Frequency Score (RIBA)	T (# Years)
1	1000
2	100
3	30
4	10
4.5	5
5	3.33333
6	0.1
7	0.01

4 Calculate the Total Risk Score

$$RS_{Total} = RS_{Safety(S)} + RS_{Environmental(E)} + RS_{Reliability(R)}$$

The determination of the 1-7 Safety, Reliability and Environmental impact and frequency scores (steps 1, 2) is below:

Reliability: The impact dimension for reliability is determined based on the number of customers served off the individual substation breaker. The calculation for the reliability impact score is:

$$Reliability\ Impact\ Score\ (R_I) = LOG(\#Customers) + 1$$

The frequency dimension for reliability is determined based on a Probability of Replacement curve adjusted by a multiplier determined by the % overstressed of the breaker

The first step to calculate the breaker frequency is to look up the initial probability of replacement calculated based on fleet performance.

Once we have the probability of replacement, we apply a multiplier depending on whether or not the breaker is overstressed such that

$$f_{R,Final} = f_{R,Initial} * Overstressed\ Multiplier$$

The multiplier is determined as follows:

Table 11
Overstressed Multiplier

% Overstressed	Overstressed Multiplier

% Overstressed > 100%	% Overstressed
% Overstressed ≤ 100%	1

For example, a 40 year old breaker with a probability of replacement per year of 1% and % overstressed = 123% has an
$f_{R,Final}$ = 1.23% = 1% * 123%

Safety: The impact dimension for substation breakers is determined by the fault current using the following table:

Table 12
Overstressed Percentage

% Overstressed	Safety Impact Score
%Overstressed ≥ 125%	4
% Overstressed < 125%	1

All distribution substation breakers received a safety frequency of 1.

The safety frequency score of 1 was determined because: Although the worst case scenario of a catastrophic failure of a substation circuit breaker causing fatalities and injuries is possible, the probability of an injury/fatality during a catastrophic circuit breaker failure is very low.

Environmental: The environmental impact score was determined based on the circuit breakers insulation medium. The impact score was determined as follows:

Table 13
Insulation Medium - Impact

% Overstressed	Environmental Impact Score
Oil, PCB ≥ 50 PPM	5
Oil, PCB < 50 PPM	2
SF_6 Gas	2
Vacuum	1

The environmental frequency score is determined based on the insulation medium as follows:

Table 14
Insulation Medium - Frequency

% Overstressed	Environmental Frequency Score
Oil	3
SF_6 Gas	3
Vacuum	1

7.3.3 Distribution OH Primary Conductor Risk Score Calculation

The following steps walk through risk score calculation for distribution substation transformers.

Figure 5
High Level Step-By-Step Risk Score Calculations for Distribution OH Primary Conductor

1. Calculate the 1-7 Safety, Reliability and Environmental Impact

2. Calculate the 1-7 frequency score

3. Calculate the $RS_{safety(S)}$, $RS_{environmental(E)}$ and $RS_{reliability(R)}$

$$RS_{S,E,R} = k^{[0.5\,\mathrm{Log}(f_{S,E,R})+I_{S,E,R}]}$$

where: f = the number of occurrences expected over a one year time horizon
and I is the impact of the event
and k is the scalar and is a fixed number of 3.16227766017085
and 0.5 is the standard risk reduction factor for aggregating the impact of uncorrelated occurrences

And $f_{S,E,R} = \frac{1}{T_{S,E,R}}$ where

Frequency Score (RIBA)	T (# Years)
1	1000
2	100
3	30
4	10
4.5	5
5	3.33333
6	0.1
7	0.01

4. Calculate the Total Risk Score

$$RS_{Total} = RS_{Safety(S)} + RS_{Environmental(E)} + RS_{Reliability(R)}$$

The determination of the 1-7 Safety, Reliability and Environmental impact and frequency scores (steps 1, 2) is below:

Reliability: The impact dimension for reliability is determined based on the number of customers served by the upstream protective device associated with the conductor line section. The calculation for the reliability impact score is:

$$Reliability\ Impact\ Score\ (R_I) = LOG(\#Customers) + 1$$

The frequency dimension for reliability is determined based on a health index calculation as follows:

Table 15
Reliability Frequency Score

Health Index (HI)	Reliability Frequency Score
HI = 1	7

0.95 ≤ HI < 1	6
0.90 ≤ HI < 0.95	5
0.80 ≤ HI < 0.90	4.5
0.65 ≤ HI < 0.80	4
0.50 ≤ HI < 0.65	3
0.25 ≤ HI < 0.50	2
HI < 0.25	1

The health index calculation is a weighted average score of several asset attributes. Each attribute is scored based on a range from 0-1. The asset attributes and their individual weightings are as follows:

Table 16
Reliability Score Details

Attribute	Value	Weight (W_i)
Age	0-1 Score See appendix (slide 9)	15%
Wire Size and Type	Normalized score (0-1) See appendix (slide 10-12)	20%
Load Current (greater than conductor rating)	Yes/No (Yes - 1, No - 0)	10%
Fault Duty (exceeding I^2t)	Yes/No (Yes - 1, No - 0)	15%
Number of splices	Thresholds See appendix (slide 13)	20%
Wind zone	Yes/No	5%
Corrosion areas	Yes/No (Yes - 1, No - 0)	15%

Each attribute score is determined as follows:

Age:
Step 1: Calculate the age for each individual line section using the following:

Table 17
OH Conductor Age Calculation

OH Install Date	Age Calculation
Install Year > Current Year	Use average line transformer age as proxy
Install Date > 1990	Use EDGIS Age data
1986 ≤ Install Date ≤ 1990	Use average line transformer age as proxy
Install Date < 1986	Use EDGIS Age data
Install Date = 1900	Use average line transformer age as proxy

Step 2: Quartile the results and assign a 0-1 score using the following:

Table 18
OH Conductor Age Quartile

Age Quartile	0-1 Score
Quartile 1 (Oldest)	1
Quartile 2	0.66
Quartile 3	0.33
Quartile 4 (Youngest)	0

Wire Size and Type:

Wire-Down site visit results were combined with wire-down metric results and system inventory to obtain wire-down rates per 100 miles. These rates were used to extrapolate a 0-1 score for all wire size and types in the system. The 0-1 score was determined based on the wire size and type using the following table:

Table 19
Wire Size and Type

Type	Wire Size	Final Score (0-1)
ACSR	3/0	0
ACSR	4	0.403846
ACSR	2	0
ACSR	1/0	0
ACSR	4/0	0
ACSR	267	0
ACSR	397	0
ACSR	795	0
ACSR	1113	0
ACSS	477	0
Aluminum	1/0	0.211538
Aluminum	3/0	0.211538
Aluminum	4/0	0.211538
Aluminum	267	0.211538
Aluminum	336	0.211538
Aluminum	397	0.134615
Aluminum	715	0.134615
Aluminum	954	0.134615
Aluminum	1113	0.134615
Copper	8	0.865385
Copper	6	1
Copper	4	0.865385
Copper	2	0.413462
Copper	1	0.413462
Copper	1/0	0.384615
Copper	2/0	0.384615
Copper	3/0	0.384615
Copper	4/0	0.384615

Copper	250	0.384615
Copper	500	0.384615
Copper	750	0.384615
Copper	4	0.865385
Copperweld	8A	0.865385
Copperweld	6A	0.865385
Copperweld	4A	0.865385
Copperweld	2A	0.865385
Copperweld	1F	0.865385

Load Current:
If the load current was greater than the conductor rating, a score of 1 was given. If the load current was not greater than the conductor rating, a score of 0 was given.

Fault Duty:
If the fault duty exceeds I^2t for a given line section a score of 1 was given, If not than a score of 0 was given.

Number of Splices:
The 0-1 score was determined based on the max number of splices in an individual phase according to the following table:

Table 20
Splice Count

Max Number of Splices in individual phase	0-1 Score
>10	1
9	0.85
8	0.7
7	0.55
6	0.40
5	0.30
4	0.20
3	0.1
< 3	0

Wind Zone:
If the line section was in a high wind zone, a score of 1 was given, if not, a score of 0 was given

Corrosion Areas:
If the line section was in corrosion zone, a score of 1 was given, if not, a score of 0 was given

Safety:
The safety impact dimension for OH Primary Conductor is a 6. A failure of an OH Primary conductor may result in public/employee fatality

The safety frequency dimension was determined based on the population density according to the following table:

Table 21
Population Density

Population Density	Safety Frequency Score
High urban area (Pop density > 1000 per sq. mile)	2
Medium/low urban area (Pop density < 1000 per sq. mile)	1

Environmental:
The environmental impact dimension for OH Primary Conductor is determined based on the possibility of starting a localized fire. For the POC, all OH Primary Conductors were given an environmental impact score of 3

All OH Primary conductors received an environmental frequency score of 1.

7.3.4 Distribution Wood Pole Risk Score Calculation

The following steps walk through risk score calculation for distribution wood poles.

Figure 6
High Level Step-By-Step Risk Score Calculations for Distribution Substation Breakers

1 Calculate the 1-7 Safety, Reliability and Environmental Impact

3 Calculate the 1-7 frequency score

4 Calculate the $RS_{safety(S)}$, $RS_{environmental(E)}$ and $RS_{reliability(R)}$

$$RS_{S,E,R} = k^{[0.5\,\mathrm{Log}(f_{S,E,R})+I_{S,E,R}]}$$

where: f = the number of occurrences expected over a one year time horizon
and I is the impact of the event
and k is the scalar and is a fixed number of 3.16227766017085
and 0.5 is the standard risk reduction factor for aggregating the impact of uncorrelated occurrences

And $f_{S,E,} = \frac{1}{T_{S,E}}$ where

And $f_R = Final\ Reject\ Rate\ (RR_{Final})$

Frequency Score (RIBA)	T (# Years)
1	1000
2	100
3	30
4	10
4.5	5
5	3.33333
6	0.1
7	0.01

5 Calculate the Total Risk Score

$$RS_{Total} = RS_{Safety(S)} + RS_{Environmental(E)} + RS_{Reliability(R)}$$

The determination of the 1-7 Safety, Reliability and Environmental impact and frequency scores (steps 1,2) is below:

Reliability: The impact dimension for reliability is determined based on the number of customers served by the upstream protective device associated with the conductor line section. The calculation for the reliability impact score is:

$$Reliability\ Impact\ Score\ (R_I) = LOG(\#Customers) + 1$$

The frequency dimension for reliability is determined based on a Reject Rate curve adjusted by a multiplier determined by the % Pole Strength of the pole

The frequency dimension for reliability is determined based on a reject rate:

Table 22
Reject Rate

Final Reject Rate (RR_{Final})	Reliability Impact Score
$RR_{Final} > 100\%$	6
$30\% < RR_{Final} \leq 100\%$	5
$20\% < RR_{Final} \leq 30\%$	4.5
$10\% < RR_{Final} \leq 20\%$	4
$3.3\% < RR_{Final} \leq 10\%$	3
$1\% < RR_{Final} \leq 3.3\%$	2
$RR_{Final} \leq 1\%$	1

Where the reject rate is determined as follows:

$$RR_{Final} = RR_{Initial} * RR_{multiplier}$$

The initial reject rate is measured based on the poles age, species and division attributes

Once we have the initial reject rate, we calculate the resulting safety factor (reject rate multiplier) by attributes

$$SF_{Resulting} = \%\ Pole\ Strength$$

Where:

$$\%\ Pole\ Strength = 1 - \left[1 - \left(2 * Shell\ Thickness * \frac{\pi}{Current\ Circumference}\right)\right]^4$$

If we have a measured value of the shell thickness, or:

$$\%\ Pole\ Strength = \frac{(Current\ Circumference)^3}{(Orignical\ Circumference)^3}$$

If we only know the current and original circumference

The multiplier is determined as follows:

Table 23
Safety Factor Multiplier

Resulting Safety Factor ($SF_{resulting}$)	Reject Rate Multiplier ($RR_{multiplier}$)
$SF_{resulting} \geq 100\%$	1
$SF_{resulting} < 100\%$	2

Safety: The safety impact dimension for all distribution wood poles is a 6. A failure of a wood pole may result in public/employee injury

The safety frequency dimension was determined based on the population density according to the following table:

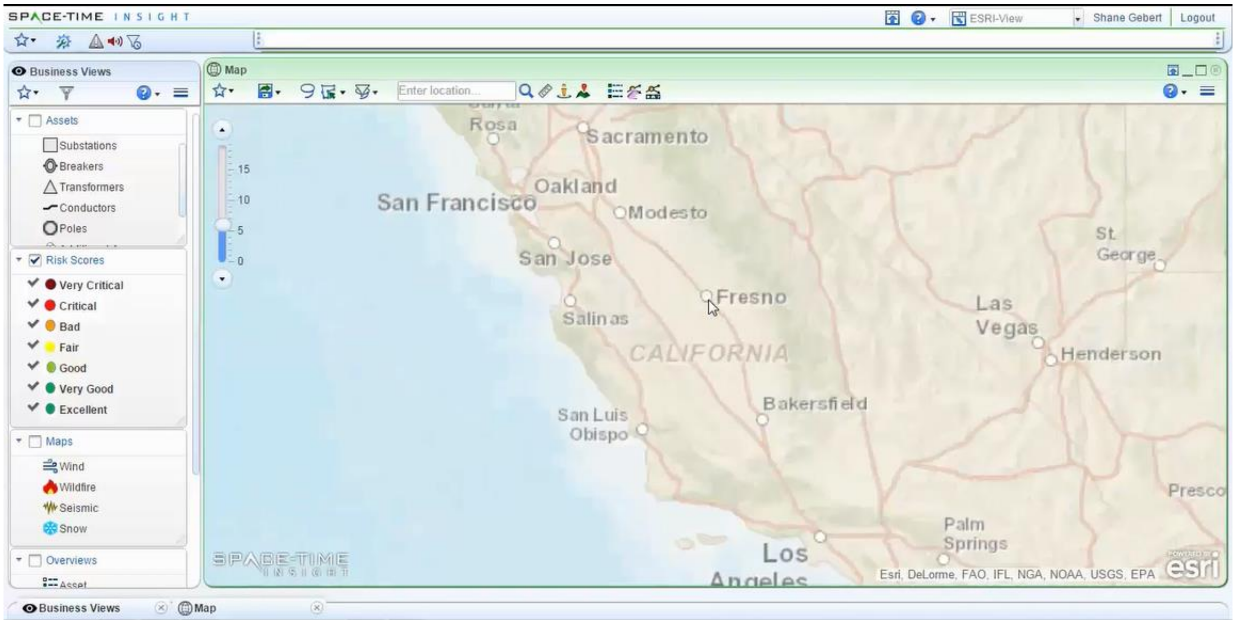
Table 24
Population Density

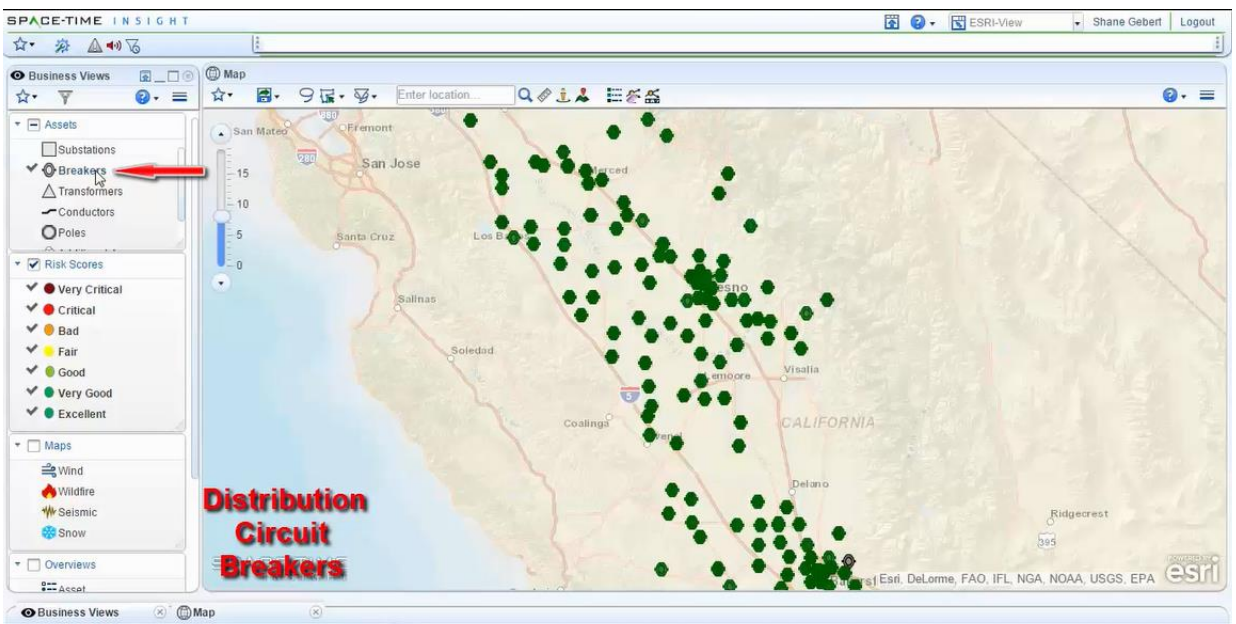
Population Density	Safety Frequency Score
High urban area (Pop density > 1000 per sq. mile)	2
Medium/low urban area (Pop density < 1000 per sq. mile)	1

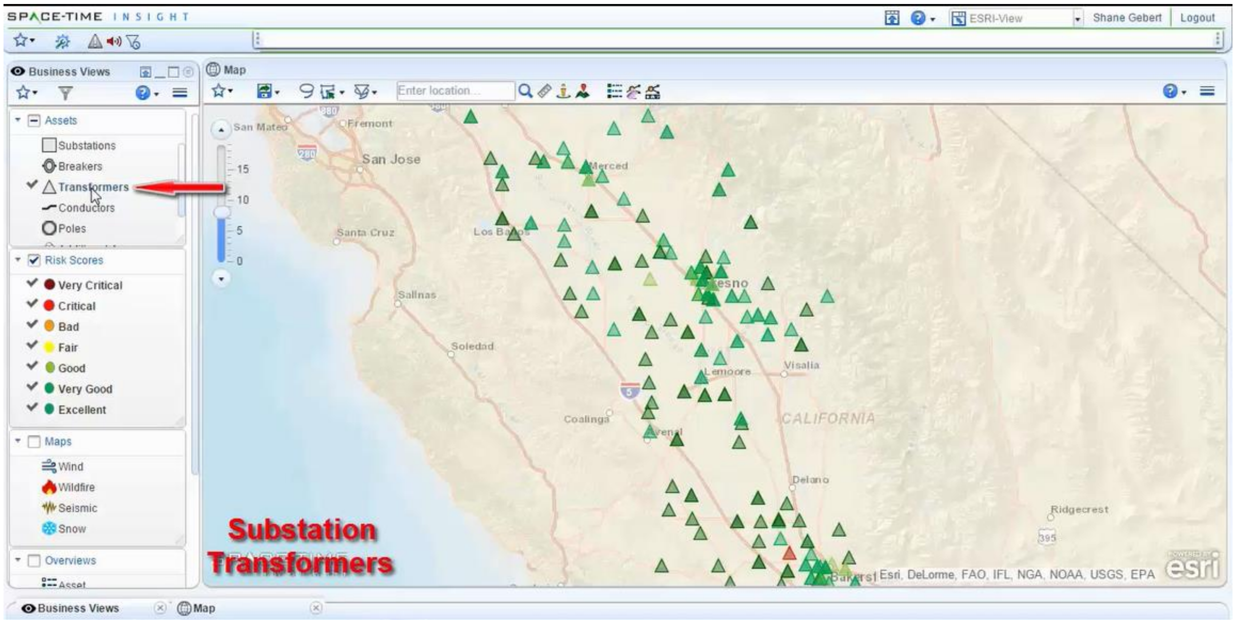
Environmental: The environmental impact dimension for distribution wood poles is determined based on the possibility of starting a localized fire. For the POC, all distribution wood poles were given an environmental impact score of 3.

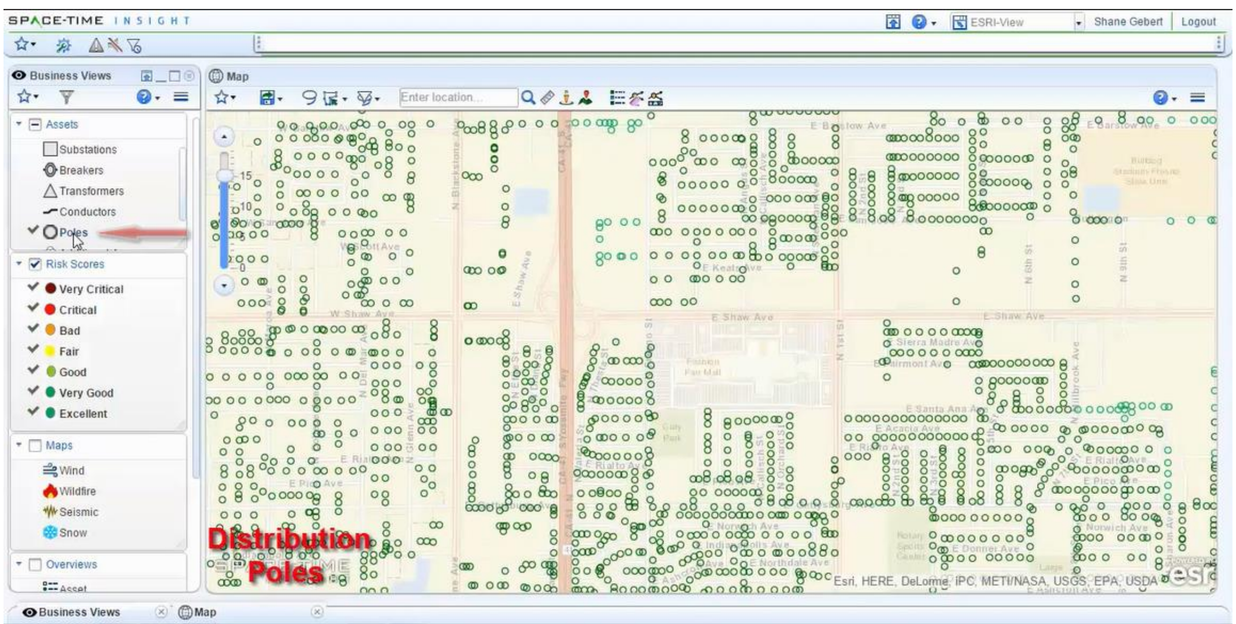
All distribution wood poles received an environmental frequency score of 1.

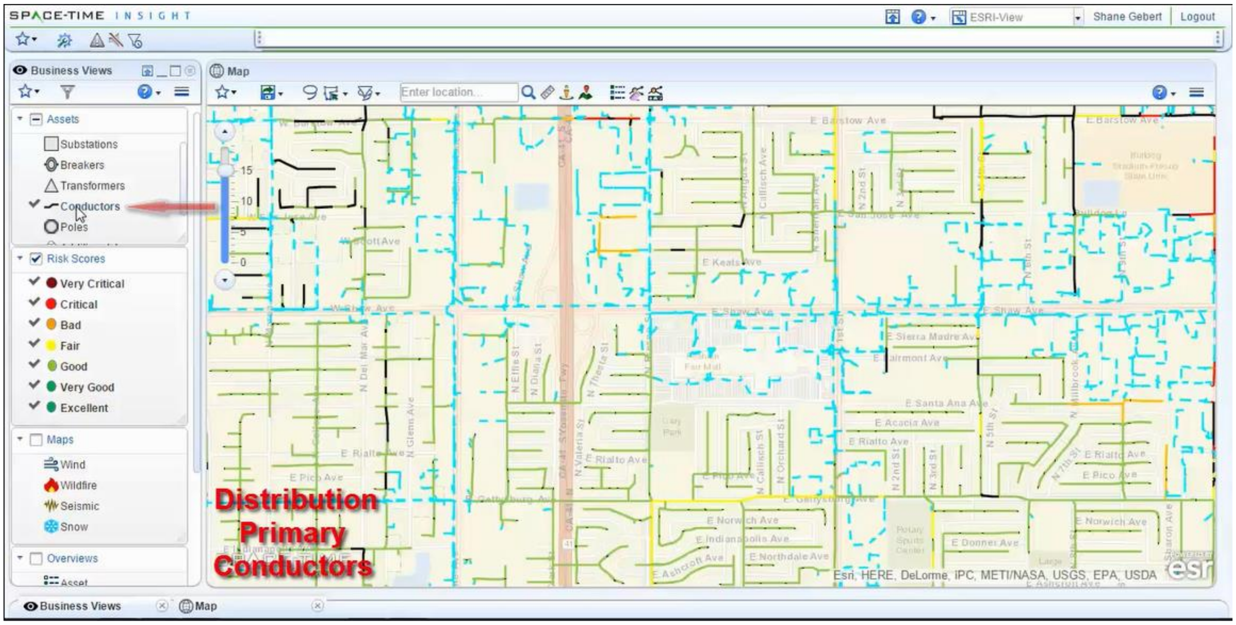
7.4 STAR POC Screenshots

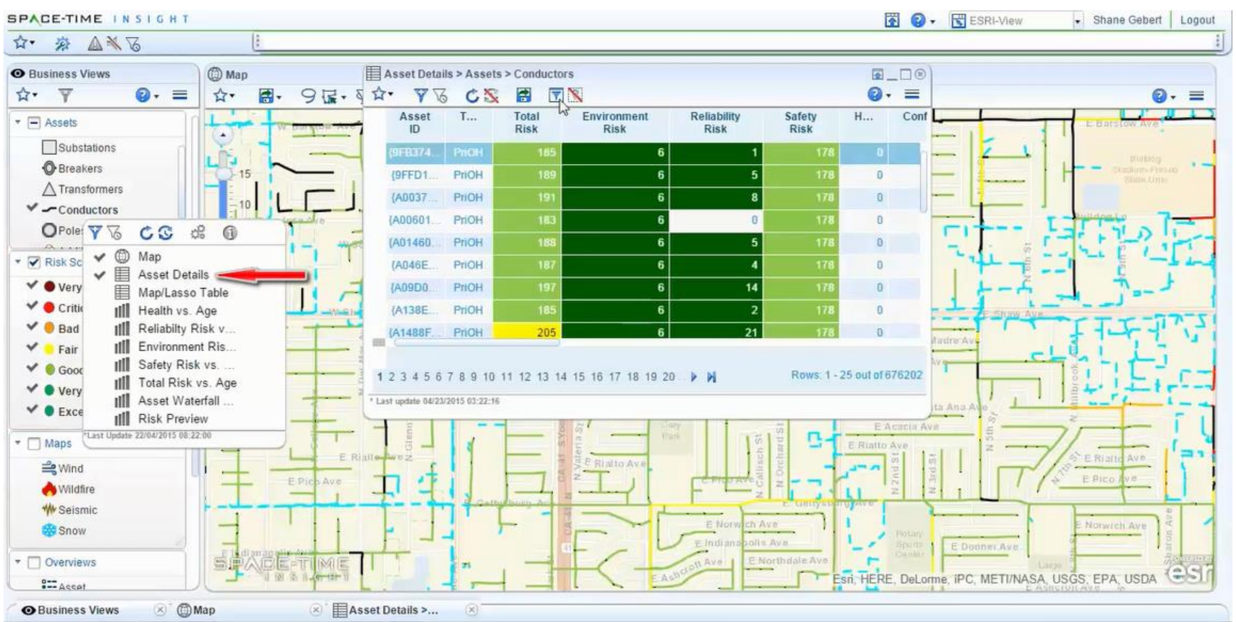


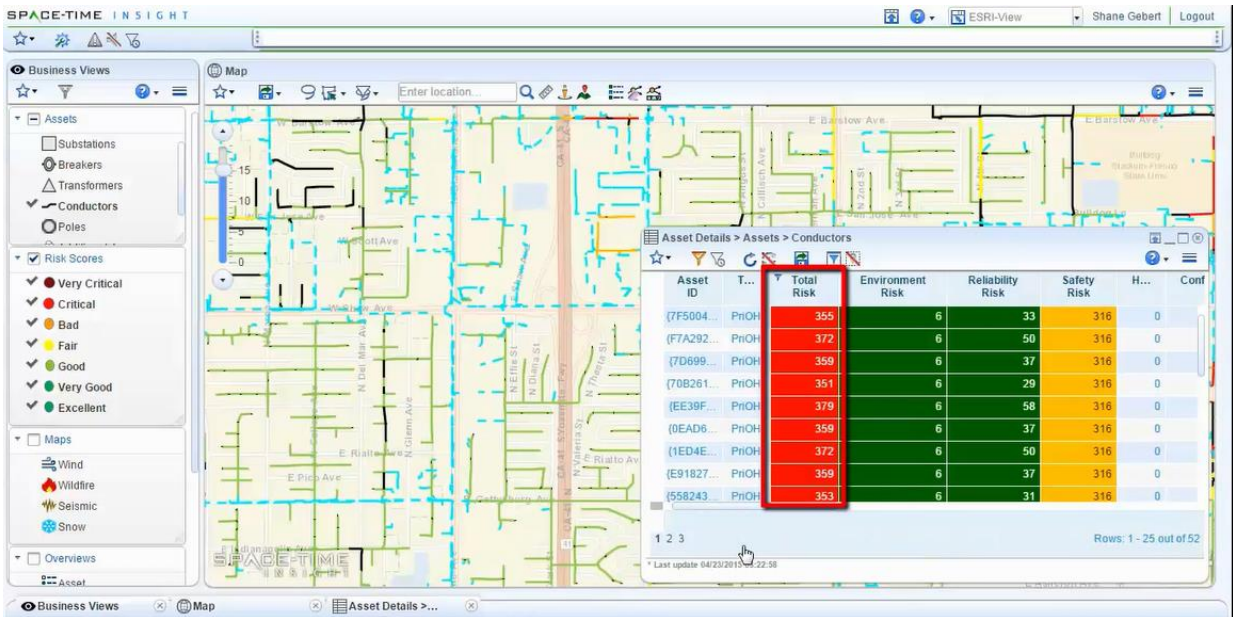



SPACE-TIME INSIGHT
ESRI-View
Shane Gebert
Logout
Business Views
Map
Enter location...
Assets
Substations
Breakers
Transformers
Conductors
Poles
Risk Scores
Very Critical
Critical
Bad
Fair
Good
Very Good
Excellent
Maps
Wind
Wildfire
Seismic
Snow
Overviews
Asset
San Mateo
Fremont
San Jose
Merced
Santa Cruz
Los Banos
Salinas
Fresno
Soledad
Lemoore
Visalia
Coalinga
CALIFORNIA
Delano
Ridgecrest
Substation
Transformers
Esri, DeLorme, FAO, IFL, NGA, NOAA, USGS, EPA
esri

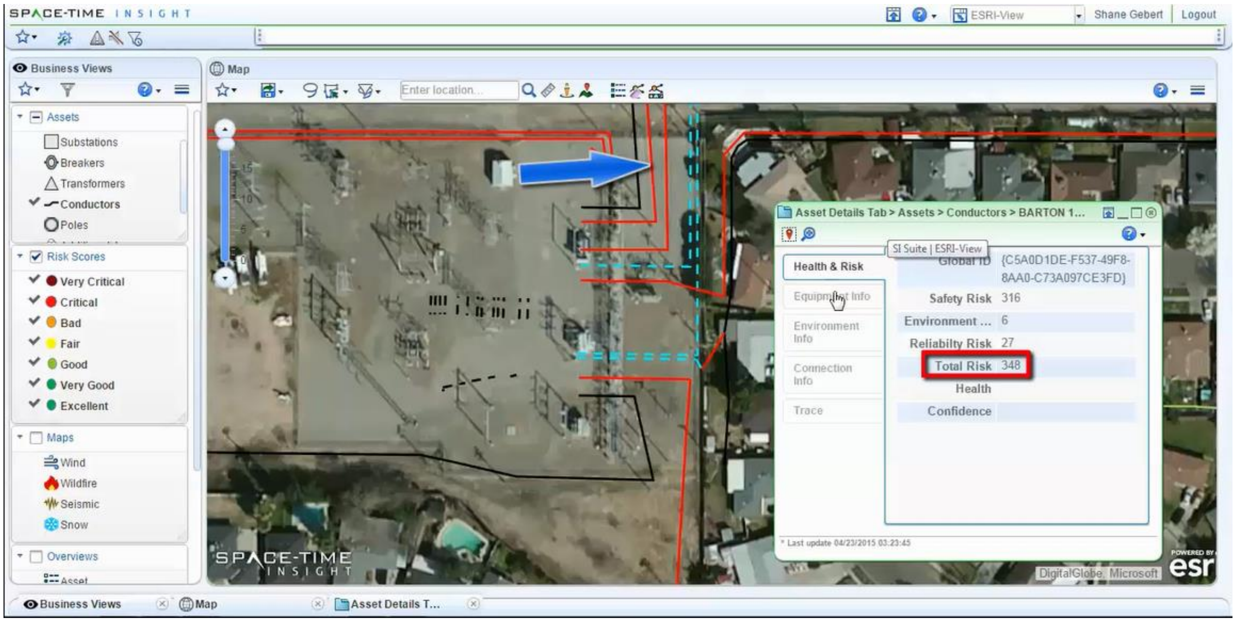

SPACE-TIME INSIGHT
ESRI-View
Shane Gebert
Logout
Business Views
Map
Enter location...
Assets
Substations
Breakers
Transformers
Conductors
Poles
Risk Scores
Very Critical
Critical
Bad
Fair
Good
Very Good
Excellent
Maps
Wind
Wildfire
Seismic
Snow
Overviews
Asset
E Shaw Ave
Distribution
Poles
Esri, HERE, DeLorme, IPC, METI/NASA, USGS, EPA, USDA
esri


SPACE-TIME INSIGHT
ESRI-View
Shane Gebert
Logout
Business Views
Map
Enter location...
Assets
Substations
Breakers
Transformers
Conductors
Poles
Risk Scores
Very Critical
Critical
Bad
Fair
Good
Very Good
Excellent
Maps
Wind
Wildfire
Seismic
Snow
Overviews
Distribution Primary Conductors
Esri, HERE, DeLorme, iPC, METI/NASA, USGS, EPA, USDA


SPACE-TIME INSIGHT
ESRI-View
Shane Gebert
Logout
Business Views
Map
Asset Details > Assets > Conductors
Asset ID
Total Risk
Environment Risk
Reliability Risk
Safety Risk
Map
Asset Details
Map/Lasso Table
Health vs. Age
Reliabilty Risk v...
Environment Ris...
Safety Risk vs. ...
Total Risk vs. Age
Asset Waterfall ...
Risk Preview
Rows: 1 - 25 out of 676202
Esri, HERE, DeLorme, iPC, METI/NASA, USGS, EPA, USDA


SPACE-TIME INSIGHT
ESRI-View
Shane Gebert
Logout
Business Views
Assets
Substations
Breakers
Transformers
Conductors
Poles
Risk Scores
Very Critical
Critical
Bad
Fair
Good
Very Good
Excellent
Maps
Wind
Wildfire
Seismic
Snow
Overviews
Map
Enter location...
Asset Details > Assets > Conductors
Asset ID
Total Risk
Environment Risk
Reliability Risk
Safety Risk
Conf
355 6 33 316 0
372 6 50 316 0
359 6 37 316 0
351 6 29 316 0
379 6 58 316 0
359 6 37 316 0
372 6 50 316 0
359 6 37 316 0
353 6 31 316 0
1 2 3
Rows: 1 - 25 out of 52
Business Views
Map
Asset Details >...


SPACE-TIME INSIGHT
ESRI-View
Shane Gebert
Logout
Business Views
Assets
Substations
Breakers
Transformers
Conductors
Poles
Risk Scores
Very Critical
Critical
Bad
Fair
Good
Very Good
Excellent
Maps
Wind
Wildfire
Seismic
Snow
Overviews
Map
Enter location...
Map Settings
Base Maps
Map Type
Imagery
100 %
Opacity
0 20 40 60 80 100
Esri Layers
WorldTimeZones
USA
World Boundaries and Places Alternate
World Reference Overlay
World Transportation
Mean Annual Temperature
Esri Overlay Features
Navigation Control
Scale Legend
Imported kml/kmz
General Settings
Map object highlight color
Show only one information...
DigitalGlobe, Microsoft
https://starpoc.com/SIServer/htmlViewer.do?moduleId=732#


SPACE-TIME INSIGHT
ESRI-View
Shane Gebert
Logout
Business Views
Assets
Substations
Breakers
Transformers
Conductors
Poles
Risk Scores
Very Critical
Critical
Bad
Fair
Good
Very Good
Excellent
Maps
Wind
Wildfire
Seismic
Snow
Overviews
Map
Enter location...
Asset Details Tab > Assets > Conductors > BARTON 1...
SI Suite | ESRI-View
Health & Risk
Equipment Info
Environment Info
Connection Info
Trace
Global ID
{C5A0D1DE-F537-49F8-8AA0-C73A097CE3FD}
Safety Risk
316
Environment ...
6
Reliabilty Risk
27
Total Risk
348
Health
Confidence
DigitalGlobe, Microsoft
Business Views
Map
Asset Details T...