EXH. DJL-9
DOCKETS UE-240004/UG-240005
2024 PSE GENERAL RATE CASE
WITNESS: DAVID J. LANDERS

BEFORE THE
WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION

WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION, Complainant, v. PUGET SOUND ENERGY, Respondent.	Docket UE-240004 Docket UG-240005

EIGHTH EXHIBIT (NONCONFIDENTIAL) TO THE PREFILED DIRECT TESTIMONY OF

DAVID J. LANDERS

ON BEHALF OF PUGET SOUND ENERGY

FEBRUARY 15, 2024

Guidehouse

Reliability Metrics Research

Final Deliverable

Gap Assessment and Recommended Reliability Metrics

Puget Sound Energy

PSE PUGET SOUND ENERGY

Contents

Executive Summary

Project Objective

PSE's SAIDI has been increasing. Likely driver appears to be weather in recent years. PSE would like to measure reliability improvements it can control and set a realistic target.

Key Questions This Project Will Answer

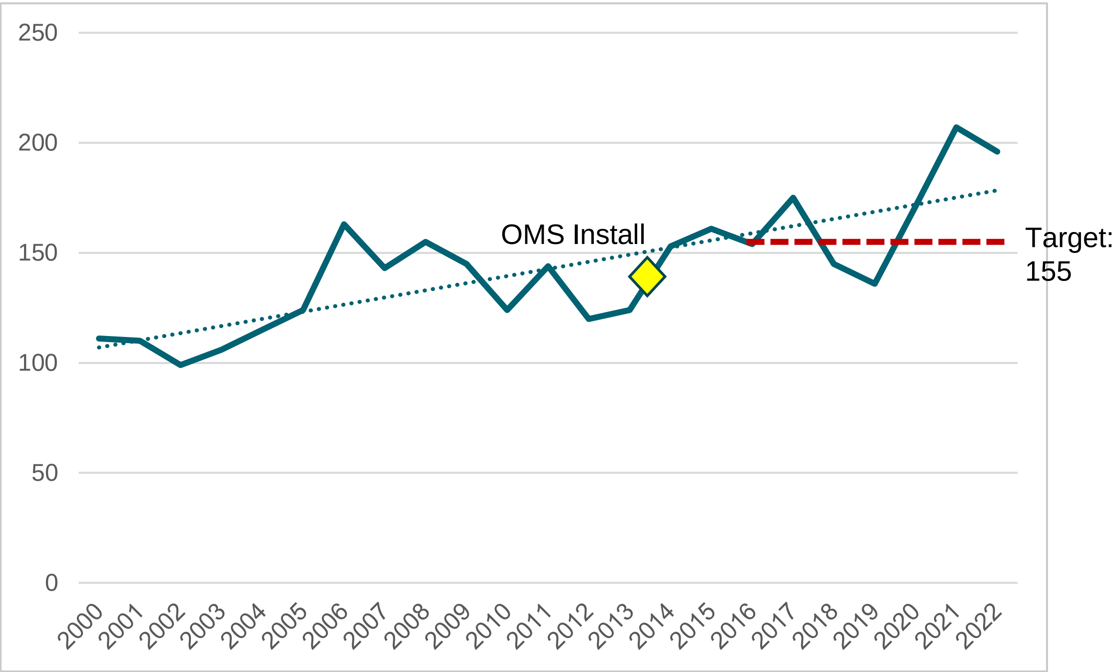
- Which reliability metrics and targets are industry peers using?
- How are industry peers calculating SAIDI/SAIFI?
  - *Deliverable 1: Comprehensive reliability metrics landscape based on industry literature, industry software offerings managing reliability, and Supplier SME inputs. Summary of key findings, observations, and comparators.* (See sections 4 and 5)
- Are alternative metrics and calculation methods appropriate for PSE?
- How can PSE control for weather and other 'noise', to isolate its own reliability performance?
- How can PSE measure improvements from its reliability programs?

?

What metrics and targets are recommended for PSE to measure reliability performance it can control?

Deliverable 2: Gap assessment and recommended metrics to consider as no-regrets options.

PSE IEEE SAIDI excluding MED



Source: PSE Service Quality and Electric Service Reliability Report. Dotted line represents linear least squares fit. Note SQI-3 SAIDI excludes catastrophic days and can be lower than IEEE SAIDI in some years (2022).

Regional Reliability Metrics Landscape

Index Name	Description	PSE	Avista	Pacific Power	Snohomish PUD	Seattle City Light	Portland General	BC Hydro	Rocky Mountain Power	Idaho Power Company	North-western Utilities	Liberty Utilities	PG&E	SCE	SDG&E	Xcel	Arizona Public Service Co
SAIFI	System Average Interruption Frequency Index	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SAIDI	System Average Interruption Duration Index	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CAIDI	Customer Average Interruption Duration Index		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CAIFI	Customer Average Interruption Frequency Index		✓														
CTAIDI	Customer Total Average Interruption Duration Index																
MAIFI/ MAIFIe	Momentary Average Interruption Frequency Index / Momentary average interruption event frequency index			✓	✓*		✓	✓	✓	✓		✓	✓	✓	✓		
ASAI / ASUI	Average Service Availability / Unavailability Index							✓									
ASIFI	Average System Interruption Frequency Index																
ASIDI	Average System Interruption Duration Index												✓				
CEMI	Customers Experiencing Multiple Interruptions	✓	✓	✓			✓	✓									
CELID	Customers Experiencing Long Interruption Duration																
CEMM	Customers Experiencing Multiple Momentaries																
CEMSMI	Customers Experiencing Multiple Sustained and Momentary Interruption																

**Snohomish County stopped reporting MAIFI in 2021*
Sources for each reliability report evaluated are available in the appendix

Regional utilities report CAIDI, MAIFI, and CEMI in recent reliability reports

- CAIDI as a reliability metric provides a level of insight into average restoration times
- MAIFI captures the impact of momentaries within the system – with increasing levels of customer-sited DERs, monitoring the frequency of momentaries within the system will be important
- CEMI provides a view into sustained interruptions experienced by customers

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National Reliability Metrics Landscape

Index Name	Description	WA	CT	DC	DE	FL	MD	MI	ND	NJ	SDG&E	PSE&G (NY)	O&R (NY)	FP&L	ComEd	PSC (NM)	ConEd
SAIFI	System Average Interruption Frequency Index	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SAIDI	System Average Interruption Duration Index	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**	✓	✓
CAIDI	Customer Average Interruption Duration Index		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CAIFI	Customer Average Interruption Frequency Index								✓								
CTAIDI	Customer Total Average Interruption Duration Index								✓								
MAIFI/ MAIFIe	Momentary Average Interruption Frequency Index / Momentary average interruption event frequency index		✓	✓		✓			✓		✓			✓			
ASAI / ASUI	Average Service Availability / Unavailability Index								✓					✓		✓	
ASIFI	Average System Interruption Frequency Index								✓								
ASIDI	Average System Interruption Duration Index								✓								
CEMI	Customers Experiencing Multiple Interruptions		✓	✓		✓	✓	✓	✓				✓	✓			
CELID	Customers Experiencing Long Interruption Duration		✓		✓*			✓									
CEMM	Customers Experiencing Multiple Momentaries		✓		✓*												
CEMSMI	Customers Experiencing Multiple Sustained and Momentary Interruption		✓						✓								

■ PSE ■ State Commissions who have ordered other reliability metrics ■ Top-performing utilities (ReliabilityOne® Award winners)

Utilities throughout the US also have used CAIDI, MAIFI, and CEMI as reliability indices; this **aligns with trends** found among the regional utilities

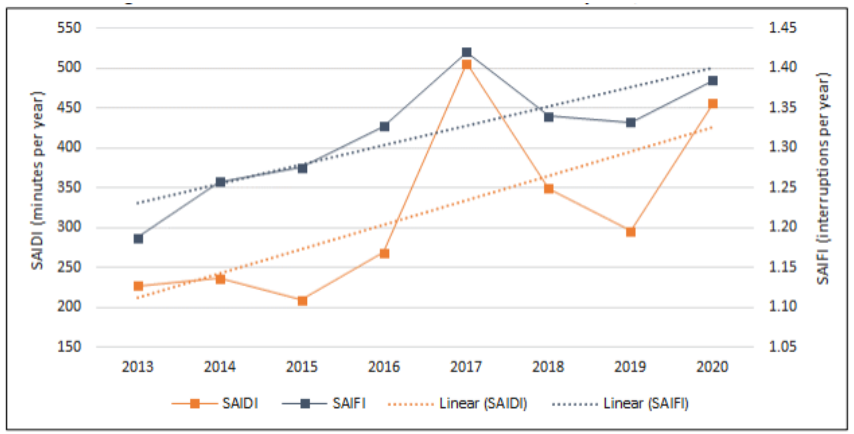
**In 2020, Delaware removed CEMI and CELID from their reliability reporting requirements. Sources for each reliability report evaluated are available in the appendix*
***ComEd doesn't cite SAIDI explicitly in its reliability report. But the state regulator has issued information requests about ComEd's SAIDI.*

Background: Reliability Metrics in the Utility Industry

SAIDI and SAIFI are industry standard, but they are not fully controllable by the utility. They also do not fully reflect customer experience. Additional reliability metrics are emerging.

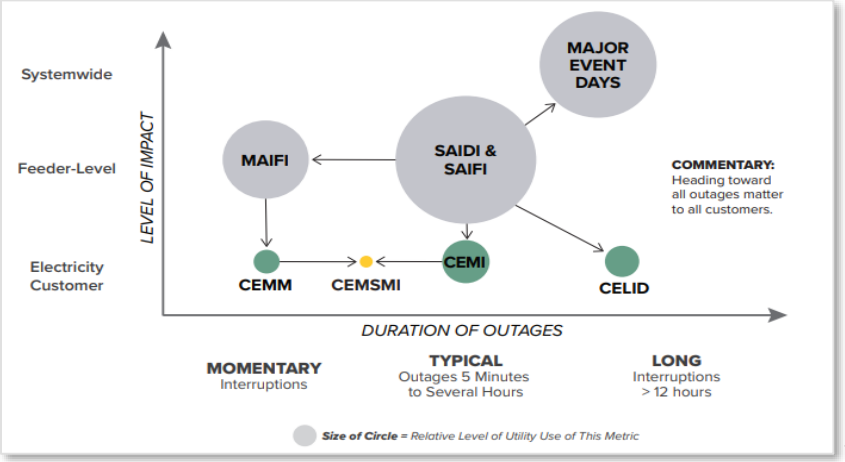
- **SAIFI, SAIDI, CAIDI and MAIFI** have been in use since 1970s
  - IEEE-1366 2012 standard allows comparison across industry and over time.
- However, **weather and other external factors drive SAIDI/SAIFI** as much as utility performance
  - *"Two-thirds of the factors that determine reliability performance are random in nature and are beyond the control of the Company." (Avista 2017 Reliability Report)*
- Total US **SAIDI and SAIFI have been increasing since 2013** (*top right*) despite grid modernization investments.
- Additionally, **SAIFI and SAIDI do not reflect**:
  - Individual **customer experience** including pockets of **least satisfied customers**
  - Impact of **momentary** interruptions on end-use services (e.g., retail business)
  - Experience of **C&I customers** (outnumbered by Residential)
  - Experience of **DER and DG customers** (momentary sensitivity)
  - Impact of **major events** and climate change
  - Interruption to **critical community services**

US Distribution System SAIDI and SAIFI since 2013



Source: NARUC depiction of EIA data

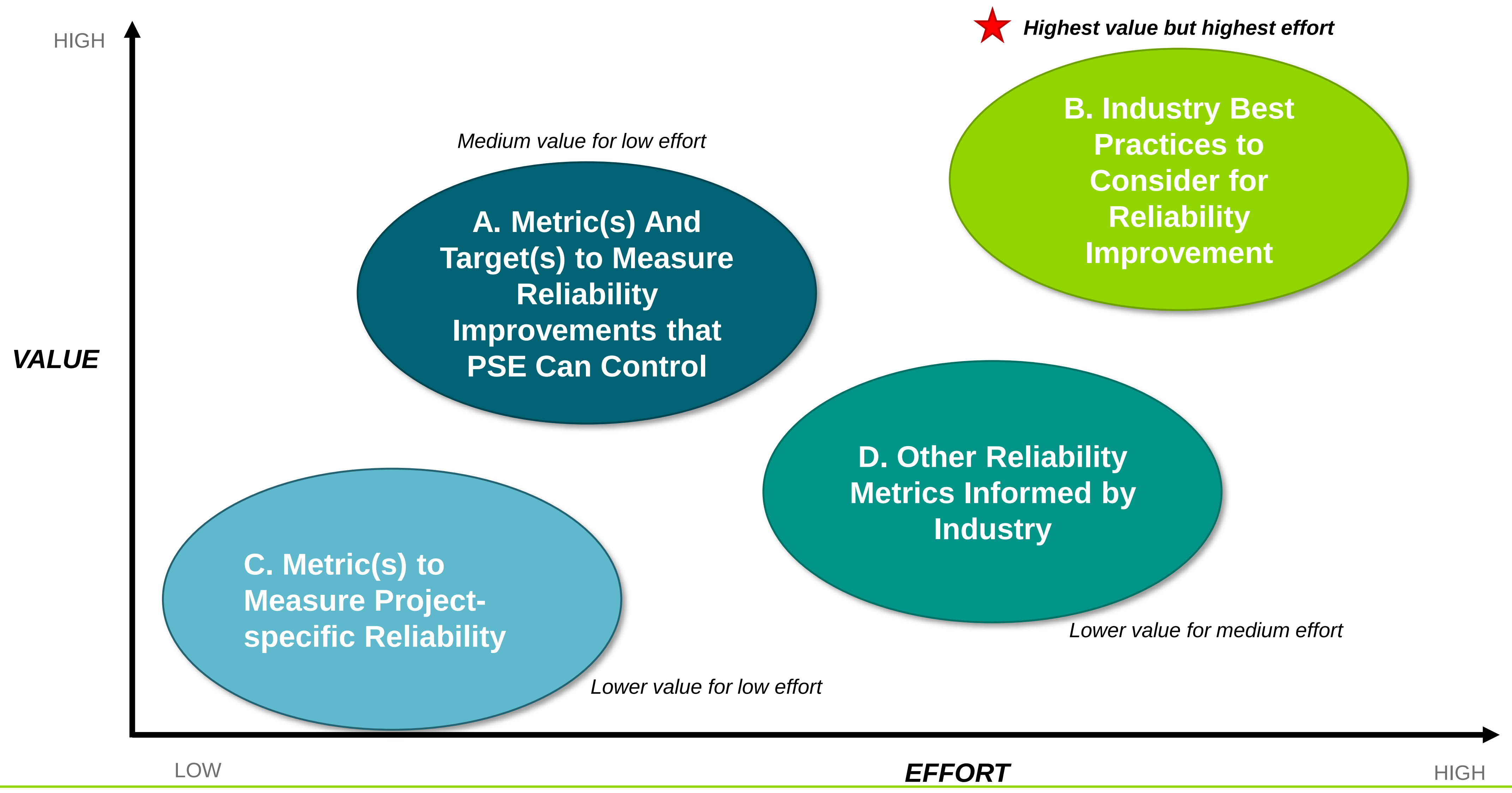
Industry evolution towards 'All outages matter to customers'



Source: Moving Beyond Average Reliability Metrics. S&C. (2020)

Recommended Reliability Metrics and Best Practices for PSE

Grouped by ease of implementation and projected value to PSE



Recommended Reliability Metrics and Best Practices for PSE

A. Metric(s) And Target(s) to Measure Reliability Improvements that PSE Can Control

1. Continue with SAIDI and SAIFI as primary metrics, but track Scheduled/Customer Requested outages separately
2. Compare performance to moving 10-year average. Set a cap on SAIDI and SAIFI at 2014-23 average plus one standard deviation
3. Track CAIDI, Response Time (aligning exclusion to SAIDI), and Repair Time
4. To normalize for weather, benchmark against neighboring utilities
5. To make metrics controllable, track blue sky SAIDI (e.g., up to 1.75B), minor storm SAIDI (up to 2.5B), and major storm SAIDI (> 2.5B). Determine B values after analysis.
6. Continue tracking controllable SAIDI (Equipment Failure + Bird/Animal)

B. Industry Best Practices to Consider for Reliability Improvement

7. Prioritize correcting abnormal conditions on emergency basis
8. Prioritize hazard tree removal. Additionally, complete tree-trimming backlog before considering any transition to risk-based or AI-based vegetation management.
9. Focus on 10 Worst Performing Circuits that contribute 10% of total SAIDI
10. Continue investments in grid automation and hardening to address leading outage causes

C. Metric(s) to Measure Project-specific Reliability

11. Continue backcasting. Consider estimating economic value of reliability improvements using DOE ICE, Energy Not Supplied metric (ENS) or Average Service Availability Index (ASAI)

D. Other Reliability Metrics Informed by Industry

12. Continue CEMI
13. Track MAIFI
14. Track ETR Accuracy

Numbering is consistent with Recommendations starting on slide 17

Project Scope and Approach

Project Scope

10-week project to recommend potential alternative approaches to PSE's reliability metrics

Task 0 – Mobilize Team & Project Management
Define roles and responsibilities from both teams, establish cadence of meetings and delivery reviews

Task 1 – Perform Industry Reliability Metrics Research
Perform industry research to deliver a comprehensive review of metrics most-applicable for use in monitoring improvements in customer reliability experience and company reliability performance.

- Research will be framed in examples of utilities operating under similar conditions as PSE considering published industry literature & research studies, examples of software systems monitoring reliability performance, and Supplier SME experience.
- Key differentiators discovered between utility practices focusing on metrics and targets will be identified
- **Deliverable 1: Comprehensive reliability metrics landscape based on industry literature, industry software offerings managing reliability, and Supplier SME inputs. Summary of key findings, observations, and comparators.**

Task 2 – Applicability Assessment and Recommendations
Supplier will interview up to 5 PSE staff regarding current practices in monitoring, considering improvements in customer reliability experience and company reliability performance, current state, and future considerations.

- Using the outcomes of Task 1 and the above interviews, Supplier will consider industry changes and evolving standards to determine if there are gaps in PSE's current practices commensurate to future metric needs.
- **Deliverable 2: Assessment of identified gaps based on research, current and future considerations of PSE, and Supplier SME inputs. Recommended metrics to consider as no-regrets options.**

Project Work Plan

Task 1

WEEK 1:
- Project charter
- Review PSE Current state of reliability metrics
- Understand practices and performance trends
- Understand peer landscape and relative performance

WEEK 2:
- Survey landscape of reliability metrics
- Create metrics inventory using literature review
- Categorize metrics by Customer, Resilience, System Availability, others as appropriate

WEEK 3:
- Interview SMEs to understand applications, pros, cons of metrics
- Begin peer research of reliability metrics practices and targets

WEEK 4:
- Complete peer research of reliability metrics practices and targets
- Begin deliverable 1: comprehensive landscape of reliability metrics based on industry literature, SME inputs and peer practices

WEEK 5:
- Present deliverable 1: comprehensive landscape of reliability metrics based on industry literature, SME inputs and peer practices

Task 2

WEEK 6: Begin Task 2 (Applicability to PSE)
- Understand PSE's outage data
- Prepare interview questions

WEEK 7
- Conduct interviews and document practices, customer reliability experience

WEEK 8:
- Gap assessment and findings

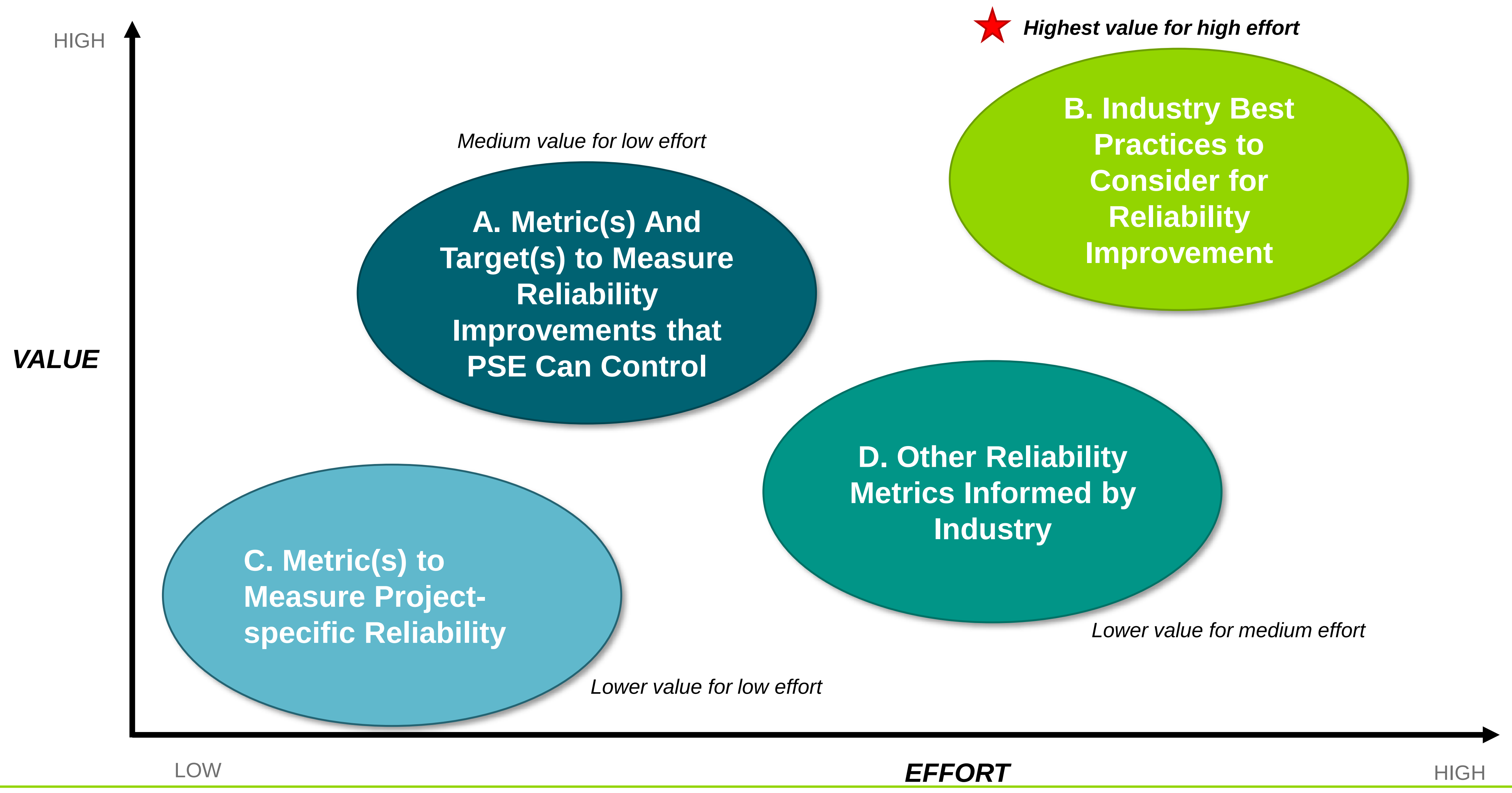
WEEK 9:
- Draft Recommendations

WEEK 10:
- Present final deliverable:
  - Assessment of identified gaps based on research, current and future considerations of PSE, and SME inputs.
  - Recommended metrics to consider as no-regrets options.

Recommended Reliability Metrics and Best Practices for PSE

Recommended Reliability Metrics and Best Practices for PSE

Grouped by ease of implementation and projected value to PSE



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D. Other Reliability Metrics Informed by Industry

12. Continue CEMI
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14. Track ETR Accuracy

Numbering is consistent with Recommendations starting on slide 17

A. Metrics And Targets to Measure Reliability Improvements PSE Can Control

1. SAIDI & SAIFI with Planned Outages Exclusion (1/3)

Continue to report SAIDI and SAIFI as your primary metrics

REGIONAL RELIABILITY METRICS LANDSCAPE

Index Name	Description	PSE	Avista	Pacific Power	Snohomish County	Seattle City Light	Portland General	BC Hydro	Rocky Mountain Power	Idaho Power Company	North-western Utilities	Liberty Utilities	PG&E	SCE	SDG&E	Xcel	Arizona Public Service Co
SAIFI	System Average Interruption Frequency Index	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SAIDI	System Average Interruption Duration Index	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CAIDI	Customer Average Interruption Duration Index		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
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CELID	Customers Experiencing Long Interruption Duration																
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Industry Best Practice

Of the regional peer utilities benchmarked, **all report SAIDI and SAIFI**.

**Snohomish County stopped reporting MAIFI in 2021*
Sources for each reliability report evaluated are available in the Appendix

1. SAIDI & SAIFI with Planned Outages Exclusion (2/3)

Continue to report SAIDI and SAIFI as your primary metrics

PSE | Top-performing utilities (ReliabilityOne® Award winners) | State Commissions who have ordered other reliability metrics

NATIONAL RELIABILITY METRICS LANDSCAPE

Index Name	Description	WA	CT	DC	DE	FL	MD	MI	ND	NJ	SDG&E	PSE&G (NY)	O&R (NY)	FP&L	ComEd	PSC (NM)	ConEd
SAIFI	System Average Interruption Frequency Index	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SAIDI	System Average Interruption Duration Index	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**	✓	✓
CAIDI	Customer Average Interruption Duration Index		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CAIFI	Customer Average Interruption Frequency Index								✓								
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CEMM	Customers Experiencing Multiple Momentaries		✓		✓*												
CEMSMI	Customers Experiencing Multiple Sustained and Momentary Interruptions		✓						✓								

Industry Best Practice

Out of the utilities benchmarked, **all 22 track SAIDI and SAIFI**. No utilities have stopped using these metrics.

*In 2020, Delaware removed CEMI and CELID from their reliability reporting requirements. Sources for each reliability report evaluated are available in the appendix

**ComEd doesn't cite SAIDI explicitly in its reliability report. But the state regulator has issued information requests about ComEd's SAIDI.

1. SAIDI & SAIFI with Planned Outages Exclusion (3/3)

Track scheduled/customer requested outages separately from SAIDI and SAIFI

- Most neighboring utilities electric utilities choose to exclude planned/scheduled outages from SAIDI and SAIFI reporting.
- Scheduled outages have constituted 6-8% of PSE's SAIDI in the last 5 years.
- Strict criteria must be applied to scheduled outages. Typically the criteria are:
  - Customer(s) must be notified 48 hours in advance
  - If a customer rejects the outage, utility must be able to reschedule (or provide backup generation).

Recommendations

- Track scheduled/customer-requested outages separately from SAIDI/SAIFI, since customers are notified in advance and customer impact is lower than other outages

Exclude Scheduled

Geographical Neighbors:
Snohomish County
Pacific Power*
Portland General Electric

Additional Utilities:
Con Edison
Florida Power and Light (NextEra)
Eversource
SDG&E
PSE&G

Include Scheduled

Geographical Neighbors:
Avista
Portland General Electric**

Additional Utilities:
AEP

* Pacific Power defines "Prearranged" outages more liberally than others. It excludes short notice emergency outages, customer requested interruptions, forced outages mandated by public authority typically regarding safety, as well as planned outages.
** Will start including planned in 2023

	2018	2019	2020	2021	2022
% SAIDI due to scheduled outages	7%	7%	8%	6%	6%
Estimated SAIDI minus scheduled outages	135	127	157	195	184

2. Compare Performance to 10-year Moving Average (1/2)

Set benchmark to moving 10-year average, with a cap at current average plus 1 std. dev.

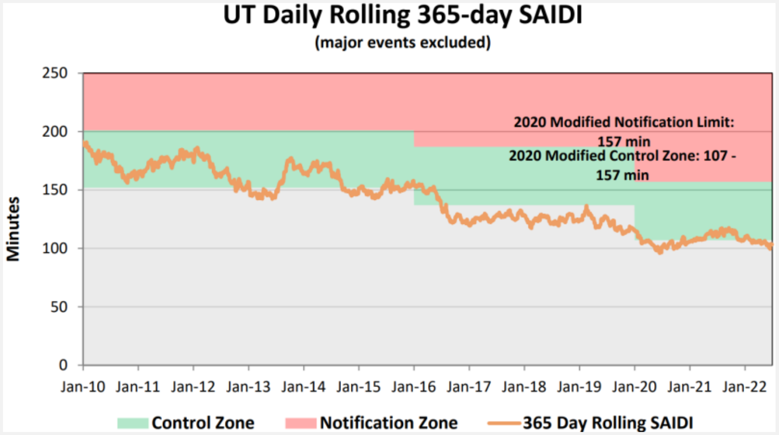
Regional Reliability Targets Landscape

Utility	Targets
PSE	Static targets established in 2016 • SAIDI target = 155 • SAIFI target = 1.2
Snohomish PUD	No target but SAIDI/SAIFI are compared with 5-year average
Avista	No target but SAIDI/SAIFI are compared with 5-year average
Pacific Power WA	Static targets established in 2003 • SAIDI target = 150 • SAIFI target = 0.9
Pacific Power CA	No target but SAIDI/SAIFI are compared with 10-year average
Idaho Power	No target but SAIDI/SAIFI are compared with 5-year average
PG&E	No target but SAIDI/SAIFI are compared with 10-year average
SDG&E	No target but SAIDI/SAIFI are compared with 10-year average
Salt River Project	Target is 10-year average plus one standard deviation
Portland General	Customers exceeding target # and duration of sustained interruptions
Rocky Mountain Power	No target but "notification limit" set at 5-year highest level

"Avista has not reported on a Target since its 2016 Reliability Report… Exceeding a target does not amount to "failure" in performance…"[1]

"Two thirds of the factors that determine annual reliability performance are random in nature and are beyond the control of the Company"[2]

- Avista Utilities



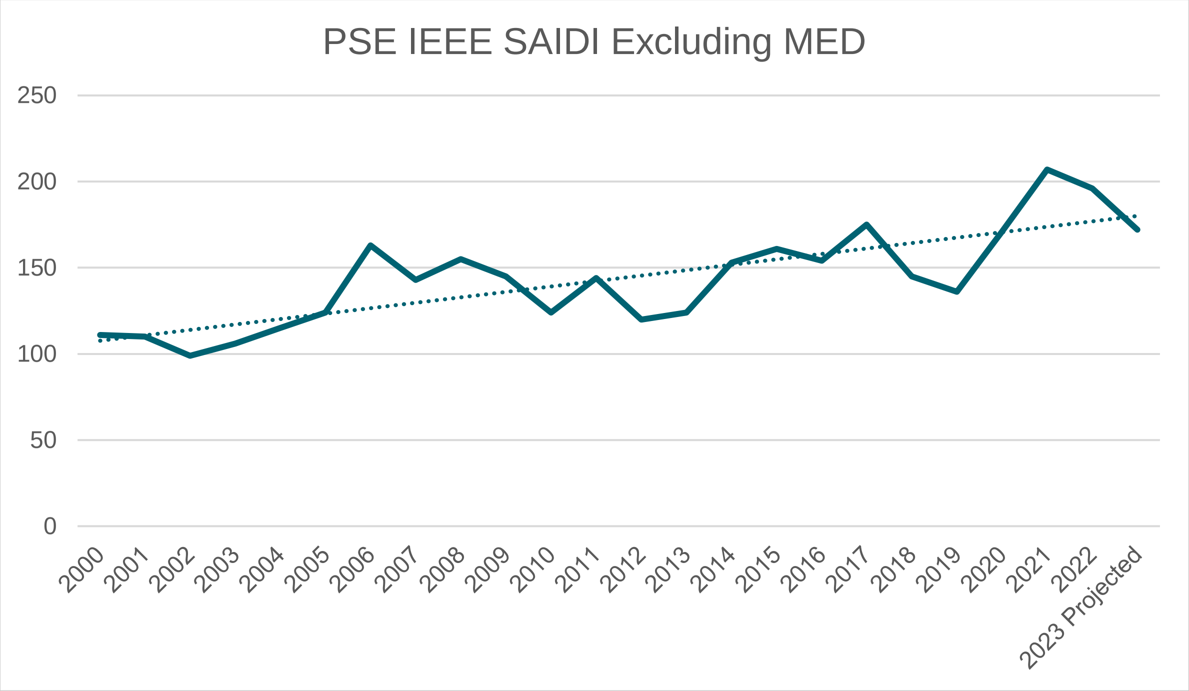
Rocky Mountain Power's SAIDI Report[3]

1. Avista 2022 Reliability report. https://apiproxy.utc.wa.gov/cases/GetDocument?docID=5&year=2023&docketNumber=230305
2. Avista 2017 Reliability report. 180376-AVA-Revised2017-Serv-Qlty-Elect-Reliability-Rpt-6-27-2018.pdf (wa.gov)
3. RMP 2022 Service Quality Report. https://pscdocs.utah.gov/electric/22docs/2203514/326017RMPSrvcQltyRvwRprtJan1Jun30202211-1-2022.pdf

2. Compare Performance to 10-year Moving Average (2/2)

Set a cap at current average plus 1 standard deviation

- PSE's recent 4 years' SAIDI values have been highest on record
- Last 5-year average (approx. 176) as a target for PSE would be considered too high
- Comparison with a longer-term average would be more advisable for PSE
- Given OMS was installed in 2013, PSE has now accumulated 10 years of post-OMS performance data (2014-2023)



Recommendations

- Compare SAIDI performance to 2014-2023 average and update it to rolling 10-year average moving forward
- Set a cap on SAIDI and SAIFI at 1 standard deviation above 2014-23 average, to avoid long-term deterioration in performance

IEEE SAIDI Excl MED	10 years (2014-23*)	5 years (2019-23*)
Mean	167	176
Std Dev	22	27
'Cap' (Mean + std dev)	189	204

* 2023 SAIDI is as projected by PSE based on January – November actuals

3. CAIDI, Response Time, and Repair Time

Track CAIDI, Response Time (after aligning exclusion to SAIDI), and Repair Time

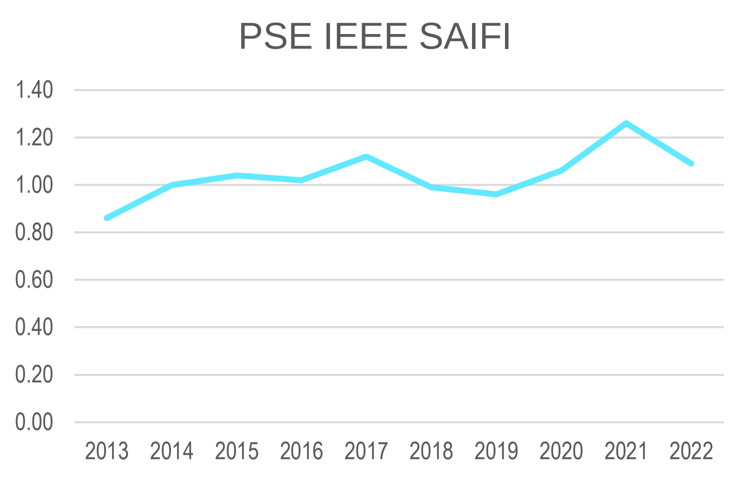
- In 2022, PSE's CAIDI was historically high. SAIFI had a dip, pointing to increasing average duration as the driver for SAIDI.

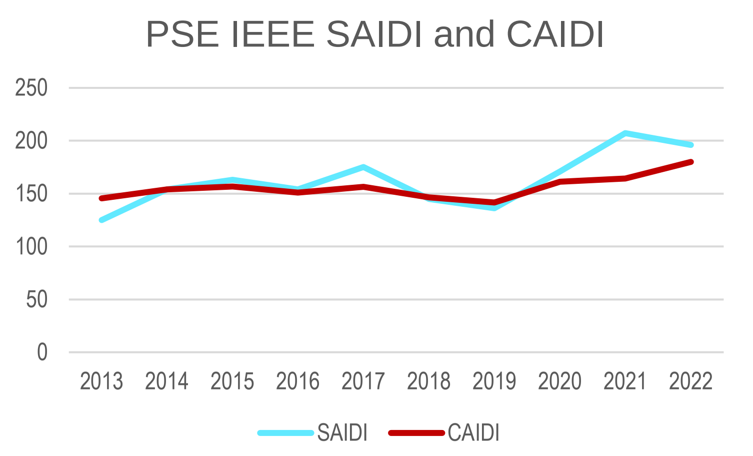
- Unlike SAIDI/SAIFI, CAIDI remained remarkably steady from 2013-2019.
    - In 2017, SAIFI and SAIDI increased but CAIDI was steady.
    - In 2019, SAIFI and SAIDI decreased but CAIDI was steady.
    - Last 3 years' CAIDI was anomalous. Why is CAIDI on the rise?

Best Practice

CAIDI is the third most frequently used metric, with 20 out of 22 benchmarked utilities using CAIDI

*CAIDI was calculated with SAIDI and SAIFI values report to UTC. Source: https://www.utc.wa.gov/regulated-industries/utilities/energy/infrastructure-and-energy-planning/annual-reliability-reports-electric-companies





	SAIDI	SAIFI	CAIDI
PSE	✓	✓	
Avista	✓	✓	✓
Pacific Power	✓	✓	✓
Snohomish County	✓	✓	✓
Seattle City Light	✓	✓	
Portland General	✓	✓	✓
BC Hydro	✓	✓	✓
Rocky Mountain Power	✓	✓	✓
Idaho Power Company	✓	✓	✓
Northwestern Utilities	✓	✓	✓
Liberty Utilities	✓	✓	✓
PG&E	✓	✓	✓
SCE	✓	✓	✓
Xcel	✓	✓	✓
APS	✓	✓	✓
SDG&E	✓	✓	✓
PSE&G (NY)	✓	✓	✓
O&R (NY)	✓	✓	✓
FP&L	✓	✓	✓
ComEd	✓	✓	✓
PSC (NM)	✓	✓	✓

3. CAIDI, Response Time, and Repair Time

Track CAIDI, Response Time (after aligning exclusion to SAIDI), and Repair Time

- PSE Electric Safety Response Time metric is defined as the average number of minutes from the time a customer calls to the arrival of the EFR personnel for electric safety incidents occurring during the performance year.
- PSE's Electric Response Time metric currently excludes the following days:
  - SQI major events when 5% or more electric customers are without power during a 24-hour period and associated carry-forward days that it will take to restore electric service to these customers ("Major Events").
  - Localized emergency event days when all available EFR in a local area are dispatched to respond to service outages or safety incidents.
- **In 2022, response time was at average level, and passed the benchmark, while CAIDI was at a historical high**
- Despite a good response time, 2022 CAIDI could be high due to:
  - Exclusions in response time
  - High repair times

PSE tracks crew dispatch time, travel time and onsite time more granularly than many utilities. Going forward, PSE is adopting the callout system to automate dispatch, further reducing response time.

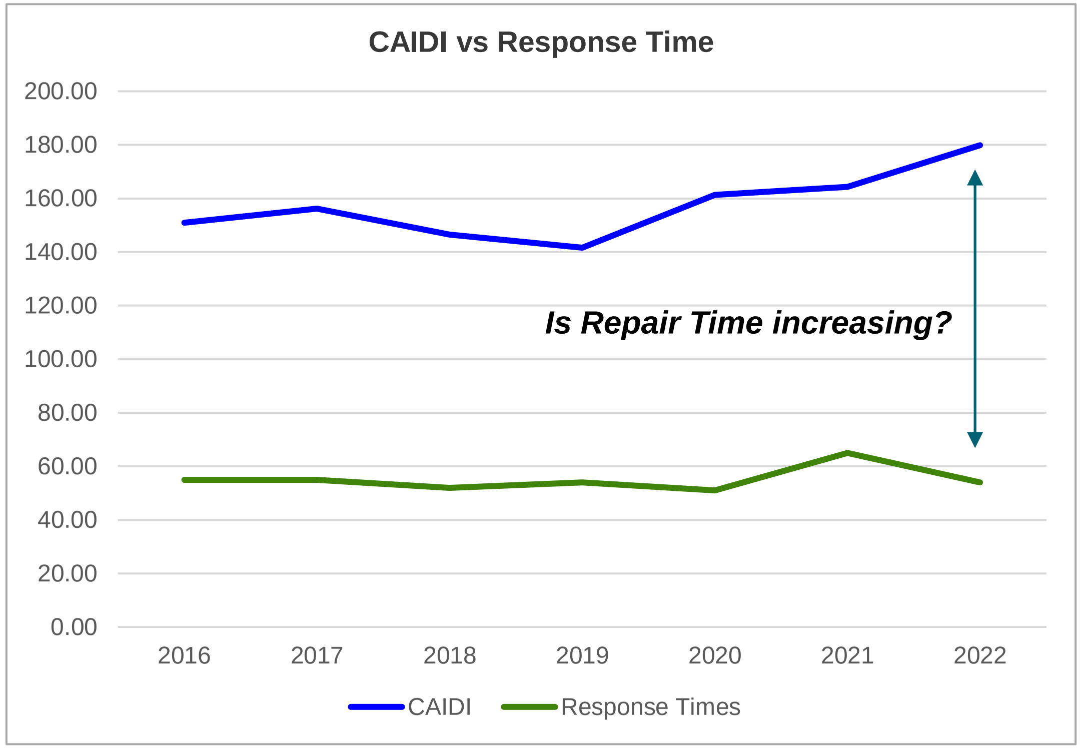
Recommendation

- Track CAIDI, Response Time and Repair Time with same exclusions as SAIDI

PSE Electric Safety Response Time

Type of Metric	Description	2022 Performance Results
Service Quality Index #11	Average 55 minutes or less from customer call to arrival of field technician	54 minutes

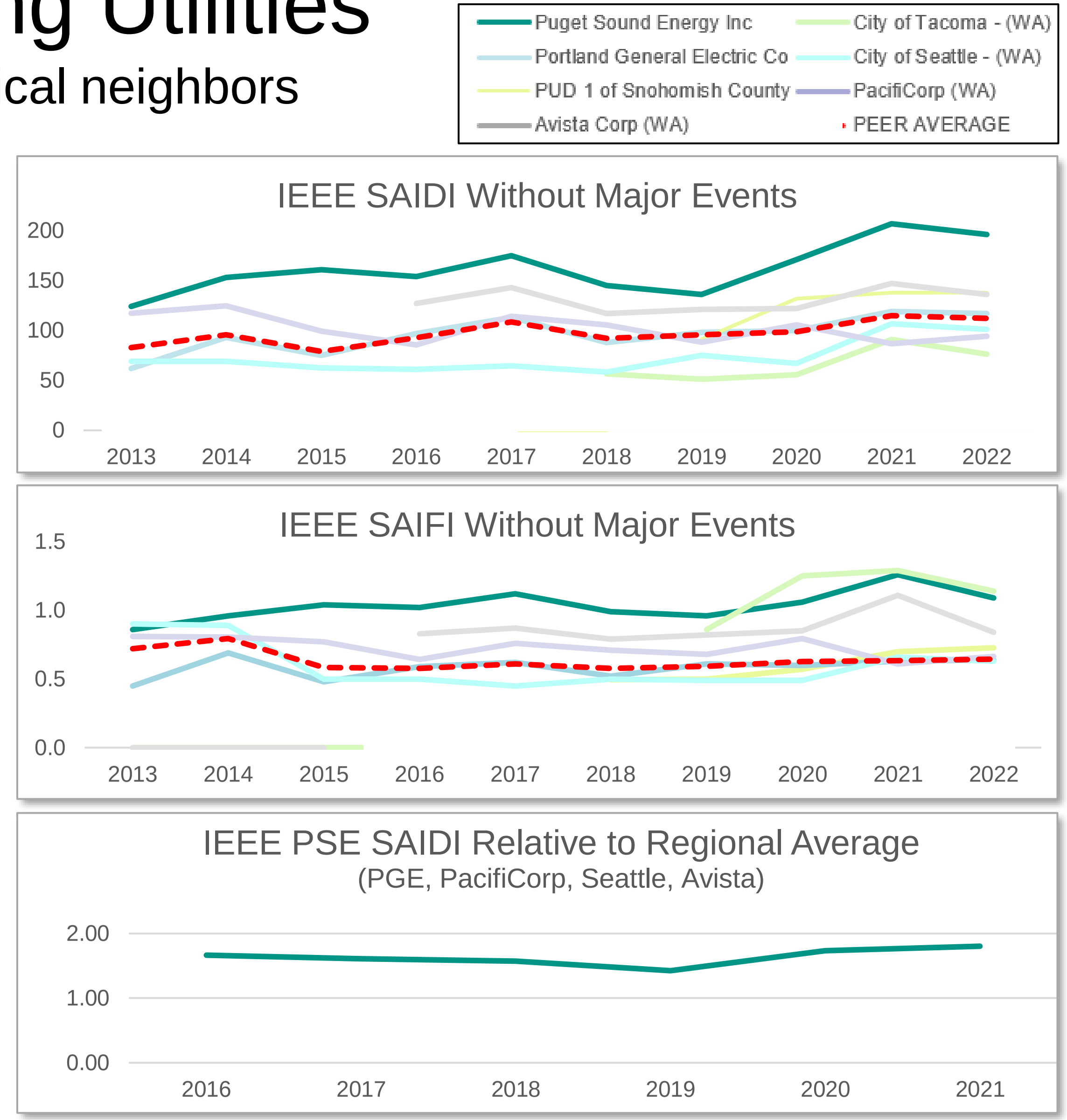
Source: PSE 2022 Service Quality and Electric Service Reliability Report



4. Benchmark against Neighboring Utilities

To normalize for weather, benchmark against geographical neighbors

- PSE can normalize SAIFI and SAIDI for weather by comparing against a regional benchmark (average of neighbors)
  - In a year when SAIDI worsens or misses target, a regional comparison would indicate if the change was weather-driven or performance-driven.
  - In a year when SAIDI improves, a regional comparison would similarly indicate if the change was weather-driven or performance-driven.
- Region's utilities collectively show a higher SAIDI in some years than others (ex. 2017, 2021). Region's utilities seem to be impacted by severe weather in certain years
- Note that the utilities on the right are geographical neighbors rather than peers. Reliability performance varies for each utility based on service territory, circuit topology, vegetation, customer density, level of undergrounding, weather and other factors.



***Sources**: EIA 861 and Guidehouse analysis*

5. Carve IEEE-SAIDI into Blue Sky and Minor Storm (1/2)

To discern weather impact on SAIDI, track Blue Sky SAIDI (e.g., up to 1.75B), Minor Storm SAIDI (up to 2.5B), and Major Storm SAIDI (> 2.5B).

- PSE's SAIDI, even after excluding IEEE major events, has significant 'noise' year on year
- It appears PSE has recently experienced several major events that have missed 2.5B threshold
- PSE would like to discern how much of its IEEE-SAIDI performance is owing to weather, and how much is controllable by basic utility operations and services

Recommendations

- To isolate PSE's blue-sky performance from weather-driven performance, carve IEEE SAIDI* into:
  1. Blue Sky SAIDI, up to a beta of about 1.75 (PSE may determine its own minor storm beta value using the analysis on the right)
  2. Minor Storm SAIDI (up to 2.5B)

Proposed Analysis Outline:

Conduct analysis to find a suitable B that discerns minor storms from blue sky

- Conduct a study in collaboration with Distribution Operations to determine which days in recent record were "blue sky", "minor storm" and "major storm", clearly defining each category.
- Determine a beta value that differentiates Blue Sky from Minor Storms respectively by fitting a distribution to your record. E.g., blue sky SAIDI might be $SAIDI_{1.75}$.
- **Track a daily SAIDI for blue sky days and a daily SAIDI for minor/major storm days, respectively.**
- Total annual blue sky SAIDI would be sensitive to the number of blue sky days, and so will have some statistical variation. If annual SAIDI is needed, define a standard year having N Blue Sky days, M minor storm days, and J major event days. Multiply daily average SAIDI by those standard counts.
- Consider hourly SAIDI units rather than daily SAIDI. IEEE methodology has a known inaccuracy of counting a Day as midnight-to-midnight, which often misses the beginning or tail end of a storm.

*IEEE SAIDI 1366-2012 Standard
Source: IEEE

5. Carve IEEE-SAIDI into Blue Sky and Minor Storm (2/2)

As an example, Pacific Power uses 1.75 Beta in addition to IEEE 2.5 Beta

- PSE considers the last three years' increase in SAIDI to be attributable to a number of storms that missed the 2.5-beta exclusion criteria.
- Most neighboring utilities had same 3-year streak of high SAIDI, corroborating the hypothesis.
- As a regional example, Pacific Power tracks its SAIDI and SAIDI using 1.75 beta exclusion criteria (excluding storms that exceed 1.75 times natural log of standard deviation of last 5 years)
- To verify the weather hypothesis, PSE can calculate SAIDI using a 1.75B exclusion method (or similar) in addition to calculating SAIDI using 2.5B

PSE – Puget Sound Energy

- PSE treats MED as calendar days per IEEE-1366/2012 (midnight to midnight)
- MED are different from SQI SAIDI and SQI SAIFI
- IEEE MED = days exceeding T_{MED} = **2.5 beta**
- SQI-3 SAIDI excludes catastrophic days from T_{MEDADJ} calculation. (Those days are replaced by 5-yr-average days.)
- Catastrophic days are days when SAIDI exceeds T_{MEDADJ} = 4.5 beta. Reasoning: Catastrophic days would increase the T_{MED} threshold too far in future years.
- Result = SQI SAIDI typically excludes more (or equal) MEDs than IEEE SAIDI
- SQI-4 SAIFI excludes MED when >5% of customers are interrupted in a 24-hour period.

Pacific Power – A Division of PacifiCorp

- Calendar days per IEEE-1366/2012 (midnight to midnight)
- SAIDI excludes days exceeding T_{MED} = **1.75 beta**
- **Days exceeding 1.75 ln std. dev.** of past 5 years mean are excluded
- No catastrophic day adjustment is applied
- SAIFI excludes days when >10% of customers simultaneously interrupted

Sources of each of the utility reliability reports evaluated are provided in the following slides

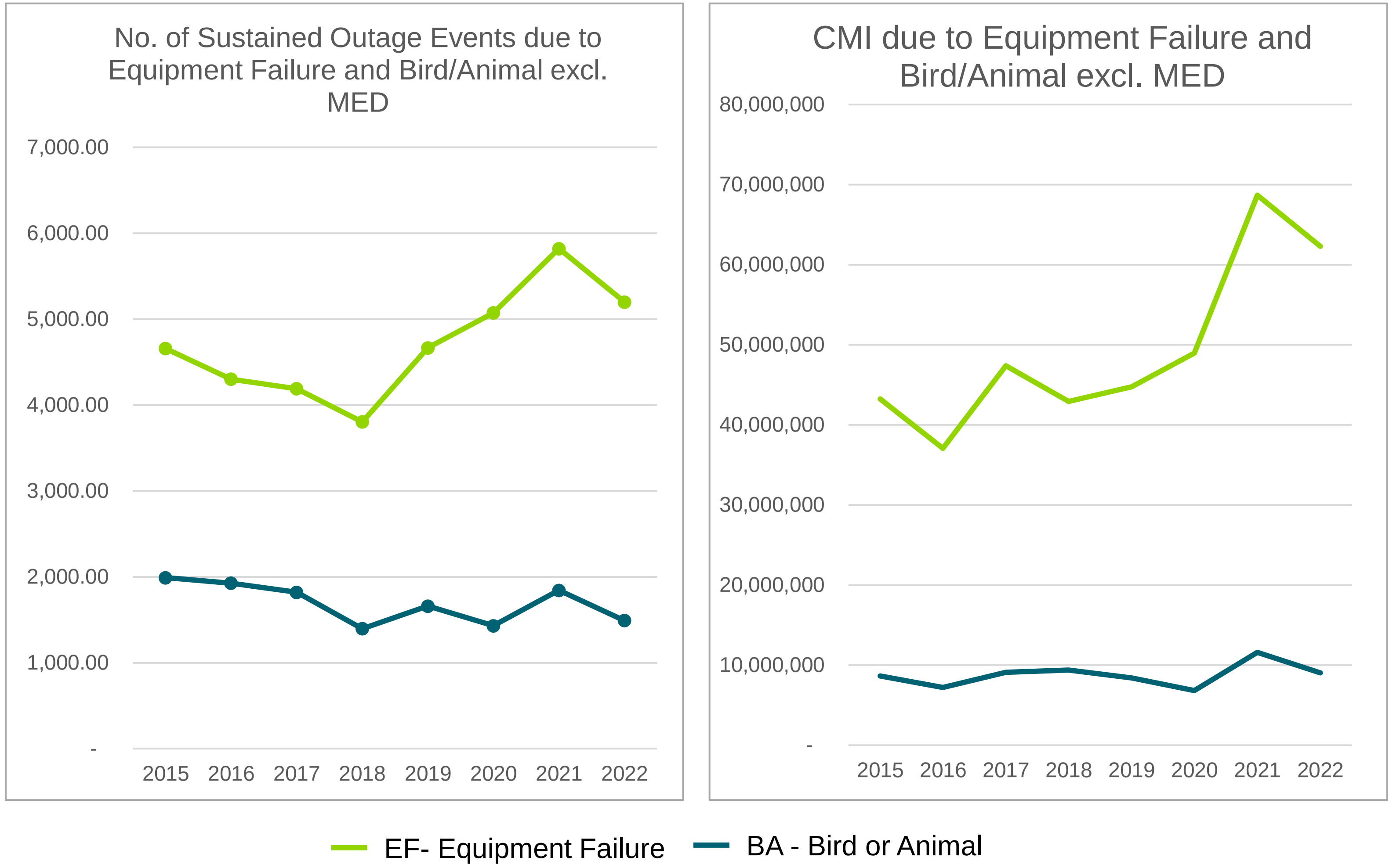
6. Track Controllable SAIDI Causes

Outages due to Equipment Failures have been increasing, and Bird/Animal have been decreasing

- **PSE Tracks "Preventable Outages"** due to Equipment Failure and Bird/Animal. This is good practice.
- **PSE's Unknown outages have been decreasing**, pointing to better documentation of outage causes.
- **PSE has identified certain assets prone to failure** and begun proactive maintenance/replacement (e.g., cables, switches)

Recommendations

- Continue tracking 'preventable' SAIDI (due to equipment failure and bird/animal)
- Analyze equipment failures to identify assets prone to failure
- Make remedial action plans for those assets
- Track ability to complete projects targeted to reduce equipment failures
- Operate / test manual switches in accordance with asset reliability programs



B. Industry Best Practices to Consider for Improvement

7. Abnormal Conditions

Prioritize the repair of abnormal conditions above other capital work.

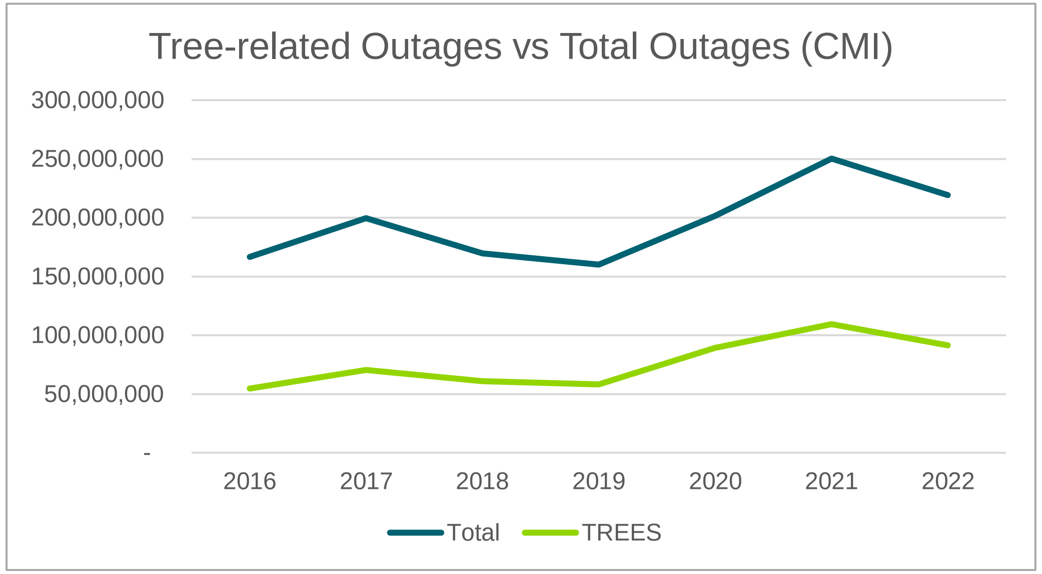
- PSE system currently has approximately 200 abnormal conditions that have been waiting for repairs. This represents significant improvement from 800 abnormal conditions three years ago.
- Abnormal conditions are likely to result in longer duration outages.
- Best practice is to treat abnormal conditions as **emergency** work orders, completing them typically in 10 days or less, and prioritizing them above capital work.
- An abnormal condition is generally considered undesirable/unacceptable among neighboring utilities. An abnormal condition reduces *n*-1 redundancy and limits a dispatcher's options to re-route and restore power – often resulting in longer outages.

Recommendations

- To drive down outage durations, PSE should treat repairing abnormal conditions as emergency work, prioritized above other capital work.

8. Hazard Tree Removal

- PSE’s TreeWatch Program was designed to remove hazard trees that pose a threat to reliability.
- Number of hazard trees removed has decreased sharply, correlated with more tree-related CMI
- PSE’s trimming cycle time of 4-6 years is consistent with industry practice. Actual trimming has fallen behind cycle. This backlog should be completed **before** PSE considers any transition to risk-based or AI-based vegetation management.



Recommendation

- Prioritize removing hazard trees as they typically cause long duration outages.
- As second priority, complete tree-trimming backlog.

9. Focused Approach to WPC

Track success in improving 10 circuits contributing 10% of total SAIDI

PSE has been tracking 135 worst-performing circuits since 2017 with related reliability projects. The SAIDI contribution of those 135 circuits has not discernably improved.

Industry Best Practice

135 circuits may be too many to manage effectively. Experiences of neighboring utilities suggests tackling a smaller number of worst offenders and targeting a short amount of time (1-2 years) to improve them.

Recommendations

- Focus on 10* circuits contributing 10% to SAIDI. Aim to get them off the list by Year 3. Move to next 10 in Year 3.
  - Number may be determined by feasible workload in a year
  - Circuit re-configuration should not be a means of getting a circuit off the list
- Once identified, PSE should track its ability to complete targeted reliability work orders on the WPC

SAIDI Contribution of 135 WPC as % of Total CMI (without MED)	2015-2017 (Average)	2020-2022 (Average)
	31%	32%

CMI Contribution of Top 10* WPC as % of Total CMI (Without MED)	WPC CMI (2020-2022)	Total CMI (2020-2022)	% Top 10 WPC from Total
	69,580,056	671,008,345	10%

***10 WPC:** SKY-25, HYA-13, SKY-23, BRS-24, GWR-13, GWR-16, CHI-12, SLA-16, ORT-22, NUG-26

10. Continue investments in grid automation and hardening to address leading outage causes

- PSE follows best practice in designing reliability programs that directly address leading outage cause codes (trees and equipment).

Table 3f: Reliability program completed work and future plans

Program Category	Outage Cause Each Program Addresses						Estimated SAIDI Savings from 2021 projects	2021 Completed	2022 Completed	2023 Plan
	Trees	BA	EF	SO	UN	Other				
Vegetation Management										
Cyclical Tree Trimming	✓						n/a	2,796 miles	2,418 miles	2,574 miles
TreeWatch	✓						n/a	1,857 trees	771 trees	750- trees
Tree Replanting	✓						n/a	On-going	On-going	On-going
Substation Landscape Renovation	✓						n/a	50 trees	50 trees	50 trees
Targeted Reliability Improvements										
Worst Performing Circuits	✓	✓	✓			✓	3 minutes	12 projects	12 projects	23 projects
Reclosers	✓	✓	✓	✓		✓	<1 minute	26 projects	27 projects	40 projects
FuseSavers	✓	✓	✓			✓	<1 minute	42 projects	38 projects	117 projects
Targeted Reliability	✓	✓	✓			✓	<1 minute	12 projects	16 projects	41 projects
Distribution Automation	✓	✓	✓	✓	✓	✓	5 minutes	3 projects	12 projects	14 projects
Substation SCADA	✓	✓	✓		✓	✓	2 minutes	10 projects	9 projects	12 projects
Transmission Automation	✓	✓	✓			✓	<1 minute	2 projects	3 projects	4 projects
Aging Infrastructure										
Cable Remediation			✓			✓	<1 minute	67 projects	23 projects	53 projects
Copper Conductor	✓		✓				n/a	n/a	n/a	6 projects
Wildfire	✓		✓			✓	TBD	1 project		1 project
Pole Inspection and Remediation			✓				TBD	38,147 poles	40,763 poles	35,478 poles
Substation Reliability			✓				<1 minute	17 projects	19 projects	28 projects
Substation Maintenance			✓				n/a	2,733 projects	2,500 projects	3,270 projects

Source: PSE 2022 Reliability Report

Recommendations

PSE should continue investments in reliability-centered programs (automation, hardening, etc.) designed to address leading outage causes.

C. Metrics to Measure Project-specific Reliability

11. Continue Backcasting. Consider Economic Value of Reliability Improvements

Potential ways to estimate economic impact of outages may include:

- **DOE ICE Calculator** – Interruption Cost Estimator by customer type and duration
- **ENS (Energy Not Supplied) and AENS (Average Energy Not Supplied)**
  - Consider to measure the amount of energy that is not delivered to customers due to power outages over a given period of time, useful to help illustrate the economic and social costs of power outages
  - ENS is calculated by multiplying the total customer interruption duration by the average customer demand
  - AENS is calculated by dividing ENS by the total number of customers served
- **ASAI (Average Service Availability Index) and ASUI (Average Service Unavailability Index)**
  - Consider to measure the percentage of time that customers receive or do not receive power service over a given period of time. Useful to compare the performance of regional power operations, and set reliability targets and benchmarks
  - ASAI is calculated by subtracting SAIDI from the total hours in the period, and dividing the result by the total hours in the period
  - ASUI is calculated by dividing SAIDI by the total hours in the period

PSE follows best practice in performing back-casting to estimate avoided SAIDI from reliability programs.

Industry Best Practice

Best practice is to perform bottoms-up estimation of avoided SAIDI from each investment/asset, rather than tracking macro-impact (like circuit SAIDI). For example, Massachusetts DPU ordered* utilities to discontinue using circuit SAIDI to evaluate reliability programs, and ordered bottoms-up case studies on specific asset operations and avoided CMI.

Recommendations

PSE should continue back-casting and track estimated CMI savings from each reliability investment, e.g.:
- Avoided CMI from removing a hazard tree
- Avoided CMI from correcting an abnormal condition
- Avoided CMI from automation of distribution or transmission system, etc.

Consider using ENS, ASUI, or DOE ICE Calculator to estimate the value of reliability improvement programs

* MA DPU Memorandum on Performance Metrics dated Nov 9, 2023 in Docket 21-8

D. Other Metrics Informed by Industry

12. Continue to track CEMI

- CEMI, Customers Experiencing Multiple Interruptions, provides insight into pockets of least satisfied customers that experienced the largest number of sustained interruptions
- Guidehouse found that 7 out of 22 benchmarked utilities track CEMI as a reliability metric. 6 out of 9 of the state commissions reviewed list CEMI as a required reliability metric in their state order

PSE currently tracks CEMI as a reliability metric

Utilities	States
Geographical Neighbors: Avista Pacific Power Portland General BC Hydro **Additional Utilities:** FP&L	**Identified States:** Connecticut Washington D.C Florida Maryland Michigan North Dakota

Industry Best Practice (Emerging)

CEMI is an emerging customer-centric metric that provides insight into the reliability experienced by the worst-served customers. This help utilities to strategically target areas to drive performance improvements for customers.

Note: List is based on assessment of utilities and states analyzed for this project. Full list is available in Appendix.

13. Track MAIFI

- MAIFI, Momentary Average Interruption Frequency Index, measures the number of customer momentary Interruptions. IEEE definition is interruptions less than 5 minutes.
- More than half (12) of the utilities analyzed has tracked MAIFI, and 3 states have MAIFI within their Commission Order

Utilities

Geographical Neighbors:
Pacific Power
Snohomish County
Portland General
BC Hydro

Additional Utilities:
Rocky Mountain Power
Idaho Power Company
Liberty Utilities
PG&E
SCE
SDG&E
O&R (NY)
FP&L

States

Identified States:
Connecticut
Florida
North Dakota

Note: List is based on assessment of utilities and states analyzed for this project. Full list is available in Appendix.

Recommendations

PSE should consider analyzing and tracking momentary interruptions in the future due to their growing importance

Industry Best Practice:

As DER penetration increases, the impact of momentaries will become more significant. Distributed generation sources are typically unable to withstand momentary interruptions and can take minutes to resume.

Retail, industrial and even residential customers are also increasingly sensitive to momentary interruptions.

14. Track ETR Accuracy

- ETR is one of the most important communications to the customer, and customers are sensitive to ETR accuracy.
- ETR accuracy matters in both ways. A restoration much earlier than ETR can also impact customers negatively. For example, a customer who was told about an 8-hour outage may start removing food from the refrigerator; if the power is restored in 2 hours the customer may not feel well-served.

Industry Best Practice:

Leading utilities track percent of customers receiving an ETR, and percent of ETRs accurate to within 90 or 120 minutes of the actual restoration.

Recommendations

- Track percent of customers receiving ETR during blue sky
- Track percent of ETR accurate within 120 minutes of the actual time of restoration
- Only the first ETR and not subsequent ETR may count towards this metric. See PSEG Long Island practice on ITR + ETR 1

How LIPA and PSEG Long Island track the ETR Accuracy Metric

T&D-32 Estimated Time of Restoration (ETR)

Allocated Incentive Compensation:	$200,000
Board Policy:	T&D System Reliability and Customer Service
Related PIPs:	None

Objective:	Provide customer with accurate estimated times of restoration in Blue Sky conditions.
Definition:	**Blue Sky ITR + ETR 1** Estimated Time of Restoration (ETR) Accuracy is the ability to provide accurate restoration estimates to customers during an outage. A passing ITR (initial time of restoration) is any restoration that is 0 to 120 minutes earlier than the ITR. Any ITR with a restoration that is 120 minutes early and 0 minutes late is considered achievement of the metric and will not be counted as a "FAILED" ETR. Any ETR 1 with a restoration that is 120 minutes early and 0 minutes late is considered achievement of the metric and will not be counted as a "FAILED" ETR. Metric measurement to commence March 1, 2022.
Calculation:	**Blue Sky ITR + ETR 1** [Number of outages restored within ITR/ETR1 tolerance] / [Total number of outages with ETRs]. Any updates greater than 1 (i.e., ETR2) is defined as a "FAIL". Any ITR restoration that is late is considered a "FAIL".
Exclusions:	OSA Minor Storms, as well as Major Storms as per NYS Department of Public Service (NYS DPS) and NYCRR 97.1.
Target:	Overall success of $\geq$ 65.0%, with metric measurement to commence March 1, 2022. Rounding protocols will allow for an overall performance of 64.95% and above to be rounded up to successfully meet the overall target of 65.0%.

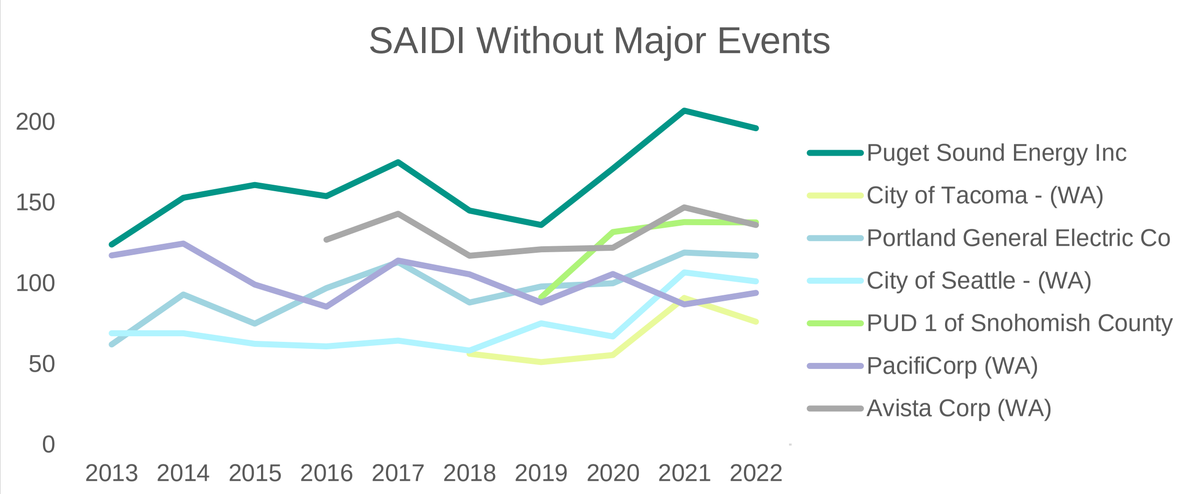
Source: LIPA 2022 OSA Metrics. PSEGLI-2022-Performance-Metrics.pdf (lipower.org)

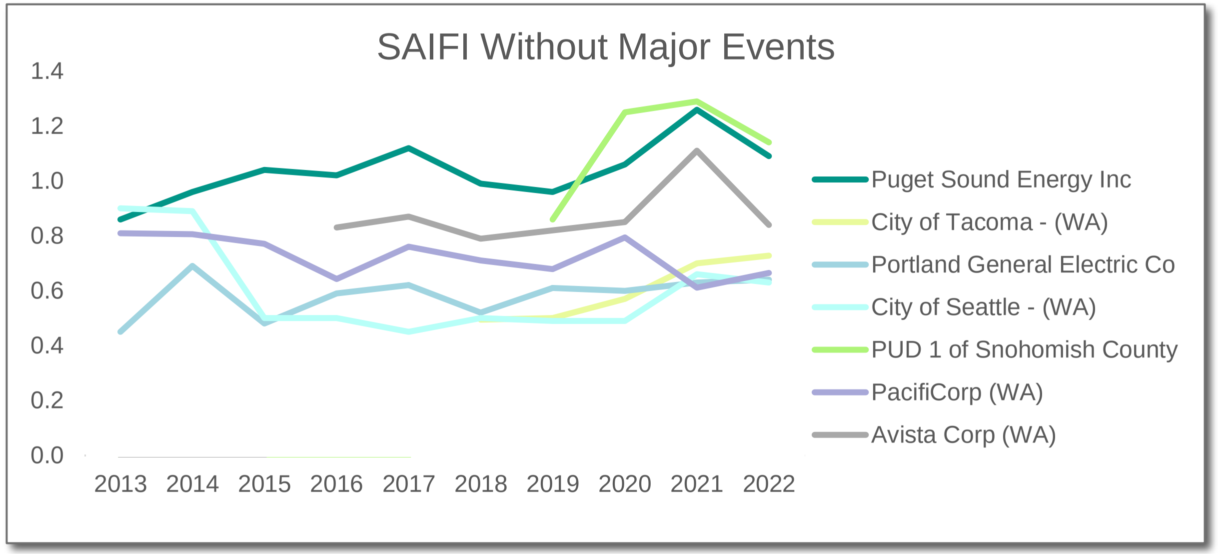
SAIFI and SAIDI Calculation Practices: Findings from PSE Comparison to Geographical Neighbors

SAIDI and SAIFI: Neighboring Utilities Comparison (without MED)

Regional performance as a whole has worsened since 2019, indicating external drivers (weather)

1. Region's utilities experience the same 'good' years and 'bad' years as a whole, suggesting reliability drivers are primarily external (rather than internal to any utility)
2. Root cause of last three years of PSE's performance is *less likely* to lie in PSE's internal practices (capital programs, reliability measurement practices, operational or maintenance procedures) than in external factors affecting the region. PSE's reliability programs would have to *outperform* neighboring utilities in order to diverge from them.
3. PSE's SAIDI and SAIFI are systematically higher than most neighboring utilities over entire period, in both 'good' and 'bad' years (deeper dive in causes in Task 2).





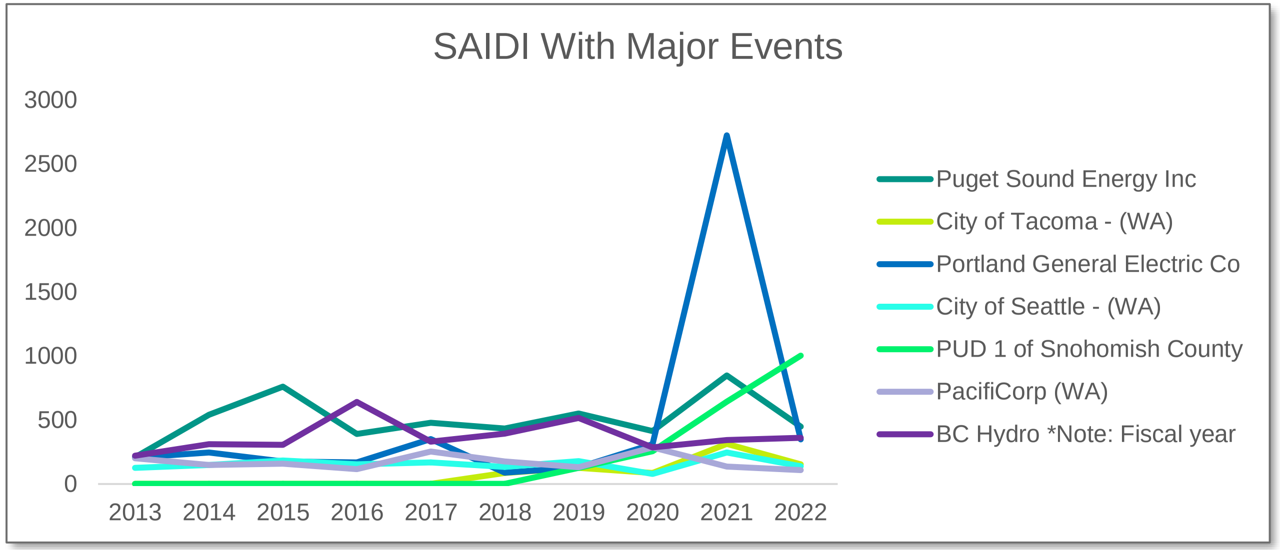
Note: PSE identified PGE, Tacoma, Seattle, Snohomish and BC Hydro as comparable peers. Plots show IEEE-1366/2012 indices, different than SQI or other company specific indices.

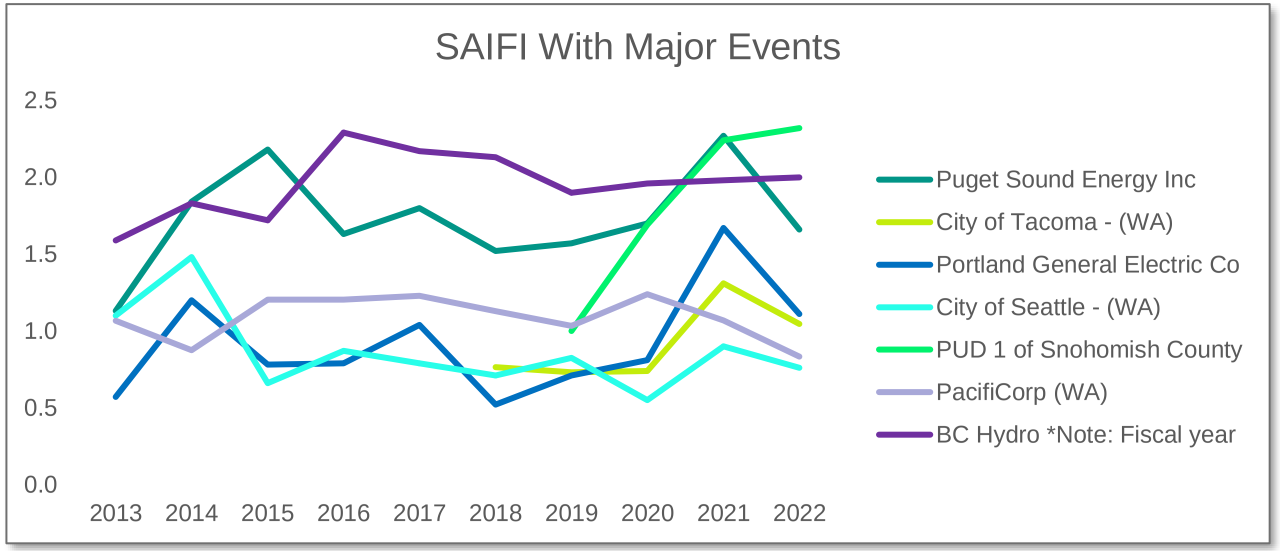
***Sources**: EIA 861 and BC Hydro Reliability Report*

SAIDI and SAIFI: Neighboring Utilities Comparison (with MED)

Reported Reliability (with MED)

1. PSE's SAIDI *with* MED is similar to neighboring utilities – in some years, it is better.
2. This is in contrast to PSE's SAIDI *without* MED which is systematically worse than neighboring utility, indicating a possible difference in MED classification criteria.
3. Region's performance with MED again varies in unison over time, suggesting that reliability drivers are primarily external.





Note: BC Hydro data includes all event indices and is not normalized
Sources: EIA 861 and BC Hydro Reliability Report

Reliability Reporting – PSE Comparison with Neighboring Utilities

	Reported metrics	Planned Outages	Major Event Threshold Beta	Targets
Puget Sound Energy	SAIDI, SAIFI, CEMI, Response Time	Included	2.5 (after excluding catastrophic days)	Targets established in 2015 and are static • SAIDI target = 155 • SAIFI target = 1.2
Snohomish County PUD	SAIDI, SAIFI, CAIDI	Excluded	2.5	Target is a 5-year average
Avista Corp.	SAIDI, SAIFI, CAIDI, CAIFI, CEMI, Average Outage Duration, Average Customers Per Outage Event, Number of Outage Events, Total CMI	Included	2.5	No target but SAIDI/SAIFI are compared with 5-year average
Pacific Power	SAIDI, SAIFI, CAIFI, MAIFI, $MAIFI_E$, CEMI	Excluded	1.75	Targets established in 2003 and are static • SAIDI target = 150 • SAIFI target = 0.9
Portland General Electric	SAIDI, SAIFI, CAIDI, $MAIFI_E$, CEMI	Excluded	2.5	Customers exceeding target # and duration of sustained interruptions

Sources for each of the utility reliability report evaluated are provided in the following slides

Reliability Report Review

Reported metrics: SAIDI, SAIFI, CEMI

- Sub-Indices:
  - Total SAIFI
  - 5-year average SAIFI
  - 5% SAIFI (to be changed to T_{MEDADJ} in 2023, matching SQI SAIDI)
  - IEEE SAIFI
  - Total SAIDI
  - 5-year average SAIDI
  - 5% SAIDI
  - IEEE SAIDI
  - SQI SAIDI
- SAIDI 5% is not IEEE standard and is not an SQI. SAIDI 5% missed three SQI MED in 2022 that were geographically concentrated. 5% SAIFI is going away. >> **SAIDI 5% index needs to be examined**.
- **Planned outages are included**

Major Event Days

- PSE treats MED as calendar days per IEEE-1366/2012 (midnight to midnight)
- MED are different from SQI SAIDI and SQI SAIFI
- IEEE MED = days exceeding T_{MED} = **2.5 beta**
- SQI-3 SAIDI excludes catastrophic days from T_{MEDADJ} calculation. (Those days are replaced by 5-yr-average days.)
- Catastrophic days are days when SAIDI exceeds T_{MEDADJ} = 4.5 beta. Reasoning: Catastrophic days would increase the T_{MED} threshold too far in future years.
- Result = SQI SAIDI typically excludes more (or equal) MEDs than IEEE SAIDI
- SQI-4 SAIFI excludes MED when >5% of customers are interrupted in an 24-hour period.

Targets

- **Targets established in 2015 after negotiations with UTC and are static** (per Order 29 of Consolidated Dockets UE-072300 and UG-072301)
- SAIDI target = 155 mins
- SAIFI target = 1.2 events (going forward 2023 per Order 24/10 of the consolidated Dockets UE-220066, UG-220067, and UG-210918 dated December 22, 2022 (“2022 GRC”))

Reliability Report Review

Reported Indices: SAIDI, SAIFI, CAIFI, MAIFI, $MAIFI_E$ (excludes MAIFI associated with sustained events), CEMI-3, CPI99 (circuit performance indictor), CPI05

Planned ("prearranged") outages are excluded (e.g., short notice emergency prearranged outages, customer requested interruptions, forced outages mandated by public authority typically regarding safety, etc.)[1]

Major Event Days

- Calendar days per IEEE-1366/2012 (midnight to midnight)
- SAIDI excludes days exceeding T_{MED} = **1.75 beta**
- **Days exceeding 1.75 ln std. dev.** of past 5 years mean are excluded
- No catastrophic day adjustment is mentioned
- SAIFI excludes days when >10% of customers simultaneously interrupted

Targets

- Baselines established in 2003 and based on 1997-2002 performance
- SAIDI baseline = 150 mins
- SAIFI baseline = 0.975 events

PacifiCorp Worst Performing Circuit Targets

WASHINGTON WORST PERFORMING CIRCUITS	BASELINE	Performance 12/31/2022
PROGRAM YEAR 2017		
GURLEY 5Y358 (circuit split into 5Y850 and 5Y854)	119	28, 37
BOYER 5W118	48	66
FERNDALE 5W106	88	65
NILE 4Y1	301	348
4TH St. 5Y468	91	36
GOAL MET! TARGET SCORE = 104	129	97
PROGRAM YEAR 2016		
DRAPER 5Y156	162	38
PINE STREET (BOWMAN) 5W150	26	51
RUSSEL CREEK 5W121	23	35
TAUMARSON FEEDER 5W50	29	28
VAN BELLE 5Y312	149	30
GOAL MET! TARGET SCORE = 62	78	36

What is the difference between using 1.75 beta vs. 2.5 beta?

Answer: >6 extra MEDs[2]

Table B.2—Probability of exceeding T_{MED} as a function of multiples of β

k	p	MEDs/yr
1	0.15866	57.9
2	0.02275	8.3
2.4	0.00822	3.0
2.5	0.00621	2.3
3	0.00135	0.5
6	9.9×10^{-10}	3.6E-07

1. See p. 44 of Pacific Power's 2022 reliability report. https://apiproxy.utc.wa.gov/cases/GetDocument?docID=3&year=2023&docketNumber=230334
2. Source: IEEE-1366/2012 p. 28, using a Gaussian dataset as an example

Reliability Report Review

Reported Indices: SAIDI, SAIFI, CAIDI, CEMI, $MAIFI_E$, and customer exceeding target interruptions in 3 years.
In 2023, PGE will begin including planned interruption data in calculating system reliability indices.
Planned interruptions are defined as 24-hours notice to customers.

Major Event Days

- Exclude days exceeding T_{MED} = 2.5 beta per IEEE-1366/2012
- Events exceeding 2.5 standard deviations of past 5 years mean are excluded (in log terms)
- MED are calendar days (midnight to midnight)

Targets

Table 19: Customer Reliability Targets

Immediate Primary Source of Service Operation Voltage	# of Sustained Interruptions Target	Customers Exceeding Target Interruptions in Each of the Last Three Consecutive Years (2020-2022)		Total Hours of Sustained Interruption Target	Customers Exceeding Target Hours of Total Interruption Duration in Each of the Last Three Years (2020-2022)	
		Major Events Excluded	Major Events Included		Major Events Excluded	Major Events Included
Above 57 kV	3	0	0	9	0	0
Between 13 kV and 57 kV	4	0	0	12	0	0
Below 13 kV	6	501	1,390	18	2,974	22,298

*Source: PGE 2022 Reliability Report

Additional Notes

- PGE includes planned outages in their performance metrics
- AMI is used as a source of sustained outage data (circuits with MV90). "PGE is working to enhance the accuracy of momentary interruption data. The company is in the discovery phase of leveraging AMI to support this work. PGE recognizes that these efforts may impact momentary interruption indices and year over year comparisons."[1]
- "An initiative was undertaken in 2022 to re-configure and set new rule sets in the OMS"[1]

1. See PGE 2022 Reliability Report

Reliability Report Review

Reported Indices: SAIDI, SAIFI, CAIDI, CAIFI, CEMI, Average Outage Duration (not per customer), Average Customers Per Outage Event, Number of Outage Events, Total CMI
Avista includes planned outages in reliability metrics

Major Event Days

- Exclude days exceeding T_{MED} = 2.5 beta per IEEE-1366/2012
- Events exceeding 2.5 standard deviations of past 5 years mean are excluded (in log terms)

Targets

- Baselines for all metrics are based on the **five-year rolling average** for each metric
- Target = average plus two standard deviations. However, this **target "*has not been reported on since Avista's 2016 Customer Service Quality and Electric System Reliability Report*"**. [1]
- *"Avista's 2017 Report provides additional detail, at length, regarding the nuances of and* ***potential inefficacy of including a Reliability Target in its annual reporting****.* ***As such, Avista does not anticipate providing such information in all future reporting periods****".*[1]
- Avista's 2017 Report details shortcomings of reliability metrics and targets. "*In prior years, Avista has referred to a "target," however, this is a misnomer. This range should not be interpreted as a "level of performance" to be achieved, because two-thirds of the factors that determine annual reliability performance are random in nature and are beyond the control of the Company*." *(Avista 2017 Reliability Report)*

1. See p. 7 of Avista 2022 reliability report. https://apiproxy.utc.wa.gov/cases/GetDocument?docID=5&year=2023&docketNumber=230305

Additional Notes

- "As AMR and AMI metering reaches full implementation and the customer meter provides outage information to the OMT system through an interface, the SAIDI and CAIDI numbers are expected to increase." [2]

2. See p. 35 of Avista 2022 reliability report. https://apiproxy.utc.wa.gov/cases/GetDocument?docID=5&year=2023&docketNumber=230305

Avista’s 2017 Petition Against SAIDI and SAIFI

Avista ceased reporting against targets for SAIDI and SAIFI in 2017

Limitations of Applying System Reliability Metrics

Our industry and many regulatory commissions have naturally focused on the use of standardized reliability measures of overall system performance because they allow them to characterize with one or two values the combined performance of the utility’s system. Consequently, these system statistics are often used as the basis for setting reliability targets, or likewise, comparing reliability among a range of utilities to identify “good” and “poor” performers.[46] Single system statistics, however, as explained above and elsewhere in this report, provide no visibility into the range of reliability performance experienced across a utility’s system, the reasons for that variation, the experience and expectations of the utility’s customers, and no insight into the many complexities involved in providing acceptable service reliability to all of the utility’s customers at a reasonable cost. Because of these factors, the use of system reliability statistics to judge performance, set targets or to guide investments can have unintended consequences for the utility and its customers. The following section lists and describes some of the key limitations of the use of system reliability statistics for these purposes.

Source: Avista 2017 Service Quality Report

Reliability Report Review

Reported metrics: SAIDI, SAIFI, CAIDI
Outages that occurred during a MED, prearranged/planned outages, and outages caused by another utility were excluded
Planned ("prearranged") outages are excluded (e.g., Outages that occurred during a MED, prearranged/planned outages, and outages caused by another utility) [1]

1. See p. 8 and 9 of Snohomish County's 2022 reliability report. https://www.snopud.com/wp-content/uploads/2023/06/2022-Reliability-Report.pdf

Major Event Days

- Calendar days per IEEE-1366/2012 (midnight to midnight)
- SAIDI excludes days exceeding T_{MED} = **2.5 beta**
- **Events exceeding 2.5 standard deviations** of past 5 years mean are excluded (in log terms)

Targets

- SAIDI target = 115 mins
- SAIFI target = 1.13 events

Planned Interruptions

Utilities with top quartile reliability across the Unites States exclude planned interruptions from metrics

Utilities excluding Planned Interruptions:

- Con Edison
- Florida Power and Light (NextEra)
- Eversource
- SDG&E
- PSE&G
- Pacific Power
- PGE*

IEEE-1366/2012: “It may be advantageous to calculate reliability indices without planned interruptions in order to review performance during unplanned events.”

Source: IEEE-1366/2012

* Started including ‘Planned’ in 2022

Additional Reliability Metrics: Findings from PSE Comparison to Neighboring Utilities

Regional Reliability Metrics Landscape

Index Name	Description	PSE	Avista	Pacific Power	Snohomish County	Seattle City Light	Portland General	BC Hydro	Rocky Mountain Power	Idaho Power Company	Northwestern Utilities	Liberty Utilities	PG&E	SCE	SDG&E	Xcel	Arizona Public Service Co
SAIFI	System Average Interruption Frequency Index	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SAIDI	System Average Interruption Duration Index	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CAIDI	Customer Average Interruption Duration Index		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CAIFI	Customer Average Interruption Frequency Index		✓														
CTAIDI	Customer Total Average Interruption Duration Index																
MAIFI/ MAIFIe	Momentary Average Interruption Frequency Index / Momentary average interruption event frequency index			✓	✓*		✓	✓	✓	✓		✓	✓	✓	✓		
ASAI / ASUI	Average Service Availability / Unavailability Index							✓									
ASIFI	Average System Interruption Frequency Index																
ASIDI	Average System Interruption Duration Index												✓				
CEMI	Customers Experiencing Multiple Interruptions	✓	✓	✓			✓	✓									
CELID	Customers Experiencing Long Interruption Duration																
CEMM	Customers Experiencing Multiple Momentaries																
CEMSMI	Customers Experiencing Multiple Sustained and Momentary Interruption																

**Snohomish County stopped reporting MAIFI in 2021*
Sources for each reliability report evaluated are available in the appendix

Regional utilities report CAIDI, MAIFI, and CEMI in recent reliability reports

- CAIDI as a reliability metric provides a level of insight into average restoration times
- MAIFI captures the impact of momentaries within the system – with increasing levels of customer-sited DERs, monitoring the frequency of momentaries within the system will be important
- CEMI provides a view into sustained interruptions experienced by customers

National Reliability Metrics Landscape

Index Name	Description	WA	CT	DC	DE	FL	MD	MI	ND	NJ	SDG&E	PSE&G (NY)	O&R (NY)	FP&L	ComEd	PSC (NM)	ConEd
SAIFI	System Average Interruption Frequency Index	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SAIDI	System Average Interruption Duration Index	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**	✓	✓
CAIDI	Customer Average Interruption Duration Index		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CAIFI	Customer Average Interruption Frequency Index								✓								
CTAIDI	Customer Total Average Interruption Duration Index								✓								
MAIFI/ MAIFIe	Momentary Average Interruption Frequency Index / Momentary average interruption event frequency index		✓	✓		✓			✓		✓			✓			
ASAI / ASUI	Average Service Availability / Unavailability Index								✓					✓		✓	
ASIFI	Average System Interruption Frequency Index								✓								
ASIDI	Average System Interruption Duration Index								✓								
CEMI	Customers Experiencing Multiple Interruptions		✓	✓		✓	✓	✓	✓				✓	✓			
CELID	Customers Experiencing Long Interruption Duration		✓		✓*			✓									
CEMM	Customers Experiencing Multiple Momentaries		✓		✓*												
CEMSMI	Customers Experiencing Multiple Sustained and Momentary Interruption		✓						✓								

PSE | State Commissions who have ordered other reliability metrics | Top-performing utilities (ReliabilityOne® Award winners)

Utilities throughout the US also have used CAIDI, MAIFI, and CEMI as reliability indices; this **aligns with trends** found among the regional utilities

In 2020, Delaware removed CEMI and CELID from their reliability reporting requirements. Sources for each reliability report evaluated are available in the appendix

***ComEd doesn't cite SAIDI explicitly in its reliability report. But the state regulator has issued information requests about ComEd's SAIDI.*

Neighboring Utilities with Other IEEE-1366 Metrics

	CAIDI	CAIFI	CTAIDI	MAIFI/$MAIFI_E$	ASAI	ASIFI	ASIDI
PSE Puget Sound Energy							
Snohomish County PUD Public Utility District No. 1	✓			✓			
Avista Corp.	✓	✓					
Pacific Power A Division of PacifiCorp	✓			✓			
BC Hydro Power smart	✓			✓	✓		
Portland General Electric	✓			✓			

Other IEEE-1366 Metrics – CAIDI, CTAIDI, CAIFI

CAIDI, CTAIDI, CAIFI metrics aim to reflect reliability impacts from customer interrupt

CAIDI: Customer Average Interruption Duration Index

- Represents the average time to restore service

$$\textit{•CAIDI} = \frac{\sum \text{Customer Minutes of Interruption}}{\text{Total Number of Customers Served}} \textit{ or } \frac{\text{SAIDI}}{\text{SAIFI}}$$

CTAIDI: Customer Total Average Interruption Duration Index

- Represents the total that average customers who actually experienced an interruption were without power

$$\textit{•CTAIDI}^{1} = \frac{\sum \text{Customer Interruption Durations}}{\text{Total Number of Distinct Customers Interrupted}}$$

CAIFI: Customer Average Interruption Frequency Index

- Represents the average frequency of sustained interruptions for those customers experiencing sustained interruptions.

$$\textit{•CAIFI}^{1} = \frac{\sum \text{Total Number of Customer Interruptions}}{\text{Total Number of Distinct Customers Interrupted}}$$

PROS

- May provide a level of insight into response times
- CAIFI may help identify areas of the grid that are prone to failures

CONS

- CAIDI – if SAIFI improves faster than SAIDI, CAIDI can appear to increase[1 2]
- CAIFI – if the reliability of some feeders improved to a point where a number of customers experience no outage at all, CAIFI can increase
- Does not fully capture the experience of customers

1. Customers with multiple interruptions are counted once. *See: IEEE 1366 Standard*
2. From CAIFI and CEMI Reporting report, ""…To properly interpret any trends,[from CAIFI], it has to be augmented by the information on trend in a number of customers that experience at least one interruption" [e.g., CEMI]
CAIFI and CEMI Reporting. Canadian Electric Association
https://www.electricity.ca/files/reports/english/SCC_2013_WhitePaper_CAIFI_CEMI_E.pdf
3. Basic Reliability Analysis of Electrical Power Systems. Lackovic, V.,
https://www.cedengineering.com/userfiles/Basic%20Reliability%20Analysis%20of%20Electrical%20Power%20Systems%20R1.pdf

Other IEEE-1366 Metrics – MAIFI and $MAIFI_E$

Service disruptions caused by momentaries are rising in significance

MAIFI: Momentary Average Interruption Frequency Index

$$\bullet MAIFI = \frac{\sum \text{Total Number of Customer Momentary Interruptions}}{\text{Total Number of Customers Served}}$$

$MAIFI_E$: Momentary Event Average Interruption Frequency Index

$$MAIFI_E = \frac{\sum \text{Total Number of Customer Momentary Interruption Events}}{\text{Total Number of Customers Served}}$$

PROS

- Can provide insight to impact of momentaries to the system
- As DER penetration increases, the impact of momentaries will become more significant.
  - Distributed generation sources are typically unable to withstand momentary interruptions and can take minutes restore.

CONS

- Metric captures a system-wide average; hence does not fully capture the experience of customers

Other IEEE-1366 Metrics – ASIDI and ASIFI

ASIDI and ASIFI measure interruptions based on system load (total connected kVA served)

ASIDI: Average system interruption duration index

$$ASIDI = \frac{\sum \text{Connected kVA Duration of Load Interrupted}}{\text{Total Connected kVA Served}}$$

- **ASIFI:** Average system interruption frequency index

$$ASIFI = \frac{\sum \text{Connected kVA of Load Interrupted}}{\text{Total Connected kVA Served}}$$

PROS

- Can provide insight to performance in areas that serve few customers having large load (predominantly industrial/ commercial customers) [1]

CONS

- Size of interrupted load is typically larger for C&I customers; hence the metric may not accurately capture experience of residential customers[2]
- Collecting data on total load interrupted is more difficult than knowing number of customers interrupted[3]
- Does not fully capture the experience of customers

1. IEEE Std 1366-2012
2. CAIFI and CEMI Reporting. Canadian Electric Association https://www.electricity.ca/files/reports/english/SCC_2013_WhitePaper_CAIFI_CEMI_E.pdf
3. Basic Reliability Analysis of Electrical Power Systems. Lackovic, V., https://www.cedengineering.com/userfiles/Basic%20Reliability%20Analysis%20of%20Electrical%20Power%20Systems%20R1.pdf

Note: Theoretically, in a system with homogeneous load distribution, ASIFI would be the same as SAIFI

Other IEEE-1366 Metrics – ASAI and ASUI

ASAI/ASUI measures of the average availability/unavailability

ASAI: Average system availability index

- Represents the fraction of time that a customer has received power during the defined reporting period

$$\bullet \textbf{\textit{ASAI}} = \frac{\text{Customer Hours Service Availability}}{\text{Customer Hours Service Demand}}$$

***ASUI:** Average system unavailability index

$$\textbf{\textit{ASUI}} = 1 - \text{ASAI } \textit{or } \frac{\text{SAIDI}}{8760}$$

PROS

- Provides insight to the availability (or unavailability) of electric service

CONS

- Does not fully capture the experience of customers

Note: ASUI is not listed as a metric in IEEE 1366. For more information, see the following:

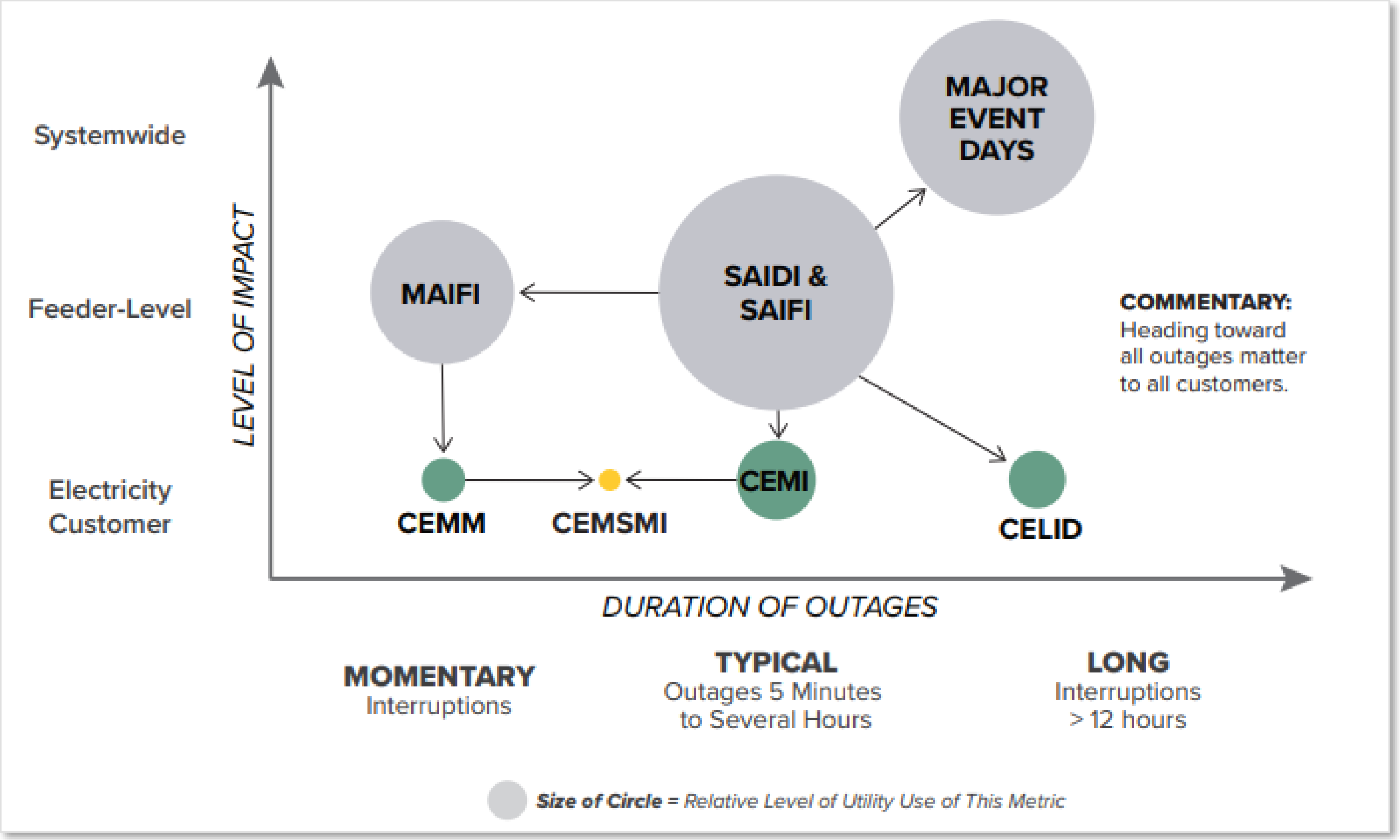
- Reliability Indices of Electric Distribution Network System Assessment; https://www.questjournals.org/jecer/papers/vol3-issue1/A310106.pdf
- Reliability Analysis of Power Distribution System: a Case Study; https://www.ijert.org/research/reliability-analysis-of-power-distribution-system-a-case-study-IJERTV6IS070290.pdf
- Pham, Hoang. *Handbook of reliability engineering*

Customer-Centric Reliability Metrics

The industry is evolving towards metrics that reflect individual customer experience, rather than average system availability

- Customers Experiencing Multiple Interruptions (CEMI)
- Customers Experiencing Long Interruption Durations (CELID)
- Customers Experiencing Multiple Momentaries (CEMM)
- Customers Experiencing Multiple Sustained Interruptions and Momentary Interruptions Events (CEMSMI)

- **The chart shows industry evolution towards customer-centric CELID and CEMI, and to some extent CEMM and CEMSMI**



Source: Moving Beyond Average Reliability Metrics. S&C. 2020.
https://ewscripps.brightspotcdn.com/db/7e/4de9f0dd4ef3b5661e3ca61d839b/electric-utility-reliabilty-metrics.pdf

Neighboring Utilities with Customer-Centric Metrics

	CEMI	CELID	CEMM	CEMSMI
PSE Puget Sound Energy	✓			
Snohomish County PUD Public Utility District No. 1				
Avista Corp.	✓			
Pacific Power A Division of PacifiCorp	✓			
BC Hydro Power smart	✓			
Portland General Electric	✓			

Customer-Centric Metrics – CEMI and CELID

CEMI and CELID provide a view into the number of customers with reliability below a threshold

CEMI: Average system interruption duration index

- Captures number of customers worst impacted by momentary interruptions
- Included in IEEE – 1366

CEMI =

$$\frac{\sum \text{Customers that experienced n or more sustained interruptions}}{\text{Total Customers Served}}$$

PROS

- Highlights experiences of worst served customers

CONS

- Does not consider momentary interruptions, hence not a holistic view of customer experience

INDUSTRY

- Identified 8 states that established CEMI as a reliability metric to report

CELID: Customers Experiencing Long Interruption Durations

- Included in IEEE – 1366

CELID =

$$\frac{\sum \text{Customers that experienced n or more hours interruption duration}}{\text{Total customers served}}$$

PROS

- Highlights impact of long interruption durations including MED

CONS

- Excludes shorter and momentary outages, so not a holistic view of customer experience

INDUSTRY

- Identified 2 states that established CELID as a reliability metric to report

Customer-Centric Metrics – CEMM and CEMSI

Although not widely used, CEMM and CEMSI give insight into the impact of momentary interruptions

CEMM: Customers Experiencing Multiple Momentaries

- Captures number of customers worst impacted by momentary interruptions
- Not included in IEEE – 1366

PROS

- Highlights impact of momentaries otherwise excluded from SAIDI/SAIDI

CONS

- Excludes longer and MED outages, so not a holistic view of customer experience

INDUSTRY

- Very few states/utilities use the metric for reliability tracking; still in its early stages

CEMSMI: : Customers Experiencing Multiple Sustained and Momentary Interruptions

- Captures interruptions of all durations
- Included in IEEE – 1366

$$\textit{CEMSMI} = \frac{\sum \text{Total Number of Customers Experiencing n or More Interruptions}}{\text{Total Customers Served}}$$

PROS

- Highlights customers worst impacted by interruptions of all durations. Captures the holistic customer experience.

CONS

- May be challenging to capture data for this metric

INDUSTRY

- Identified 2 states that established CEMSMI as a reliability metric to report

Resilience Metrics (1): Performance-Based Metrics

The Grid Modernization Laboratory Consortium (GLMC) categorizes resilience metrics into: multi-criteria decision analysis and performance based metrics.

Performance-Based Resilience Metrics

How would an investment impact the resilience of the electric system?

- Measure the potential benefits and costs associated with proposed resilience enhancements and investments.
  - Ideal for cost-benefit and planning analyses
- Required data can be gathered from historical events, subject matter estimates, or computational infrastructure models.

- Note: Oregon Public Utility Commission led a Resilience Workshop on June 2022, featuring performance metrics and multi-criteria metrics (next page)

Consequence Category	Resilience Metric
Direct	
Electrical Service	Cumulative customer-hours of outages Cumulative customer energy demand not served Average number (or percentage) of customers experiencing an outage during a specified time period
Critical Electrical Service	Cumulative critical customer-hours of outages Critical customer energy demand not served Average number (or percentage) of critical loads that experience an outage
Restoration	Time to recovery Cost of recovery
Monetary	Loss of utility revenue Cost of grid damages (e.g., repair or replace lines, transformers) Cost of recovery Avoided outage cost
Indirect	
Community Function	Critical services without power (e.g., hospitals, fire stations, police stations) Critical services without power for more than *N* hours (e.g., *N* > hours of backup fuel requirement)
Monetary	Loss of assets and perishables Business interruption costs Impact on Gross Municipal Product or Gross Regional Product
Other Critical Assets	Key production facilities without power Key military facilities without power

Petit F, Vargas V, Kavicky J. 2020. Grid Modernization: Metrics Analysis (GMLC1.1) – Resilience. PNNL-28567. April 2020. U.S. DOE Grid Modernization Laboratory Consortium. https://gmlc.doe.gov/sites/default/files/resources/GMLC1.1_Vol3_Resilience.pdf

Resilience Metrics (2): Multi-Criteria Decision Analysis

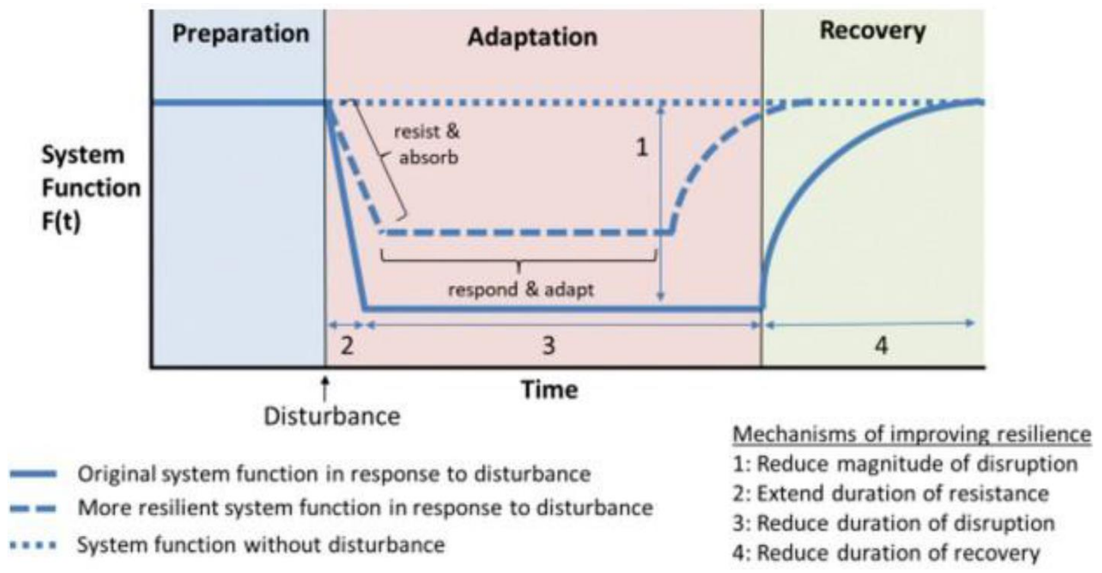
The Grid Modernization Lab Consortium (GLMC) categorizes resilience metrics into: multi-criteria decision analysis and performance-based metrics.

Multi-Criteria Decision Analysis

What is the current state of the resilience of the electric system, and what are the options to enhance its resilience over time?

- Provide a baseline to understand the system's current resilience and facilitate consideration of resilience enhancement options
- The application of these metrics typically requires that analysts follow a process to review their system and determine the degree to which the properties are present within the system.
- These determinations are usually made by collecting survey responses, developing a set of weighting values that represent the relative importance of the survey responses, and performing a series of calculations that result in numerical scores for the resilience attributes.

Preparedness Anticipate	Mitigation Resist, Absorb	Response Respond, Adapt	Recovery Recover
Define the hazard environment	Prior to an event, plan how to reduce the severity or consequences of a hazard	Manage the adverse effects of an event	Return conditions to an acceptable level of operations



Source: Department of Energy and National Association of Regulatory Utility Commissioners (NARUC), Resiliency Reference Guide, 2023. https://pubs.naruc.org/pub/1C098515-1866-DAAC-99FB-3FBA6FA3AB0B

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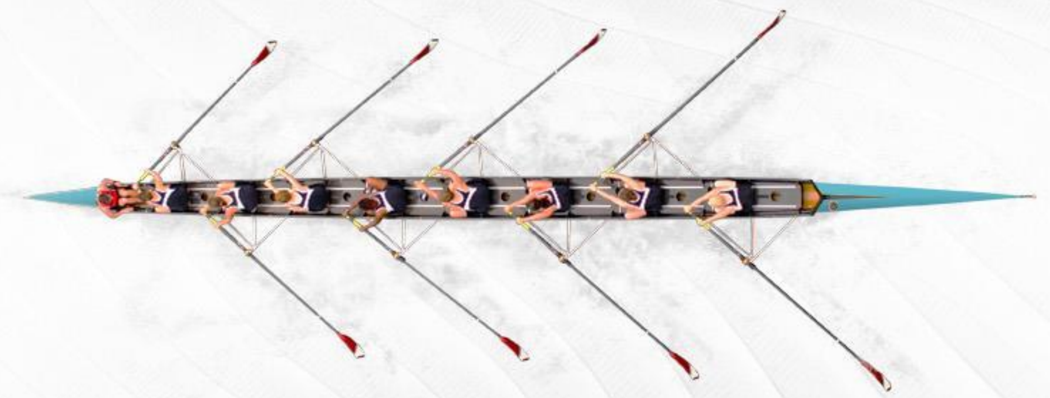

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