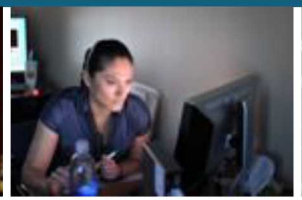
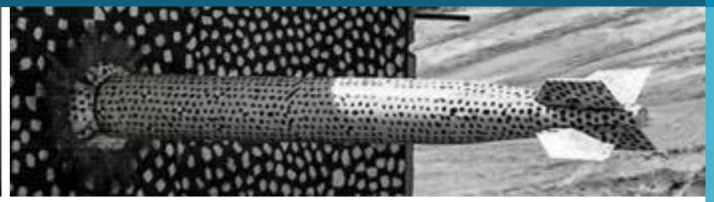
Sandia National Laboratories

SAND2019-11000PE

Leveraging Empirical Data to Characterize PV O&M Issues





PRESENTED BY

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DOE Solar Colloquium

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Outline

1. Background & Motivation
2. PVROM Database
3. Research Activities
    1. Weather Impacts
    2. Failure Distributions
    3. Common Failure Modes
4. Synergistic Discussions

Changing Costs with Growth

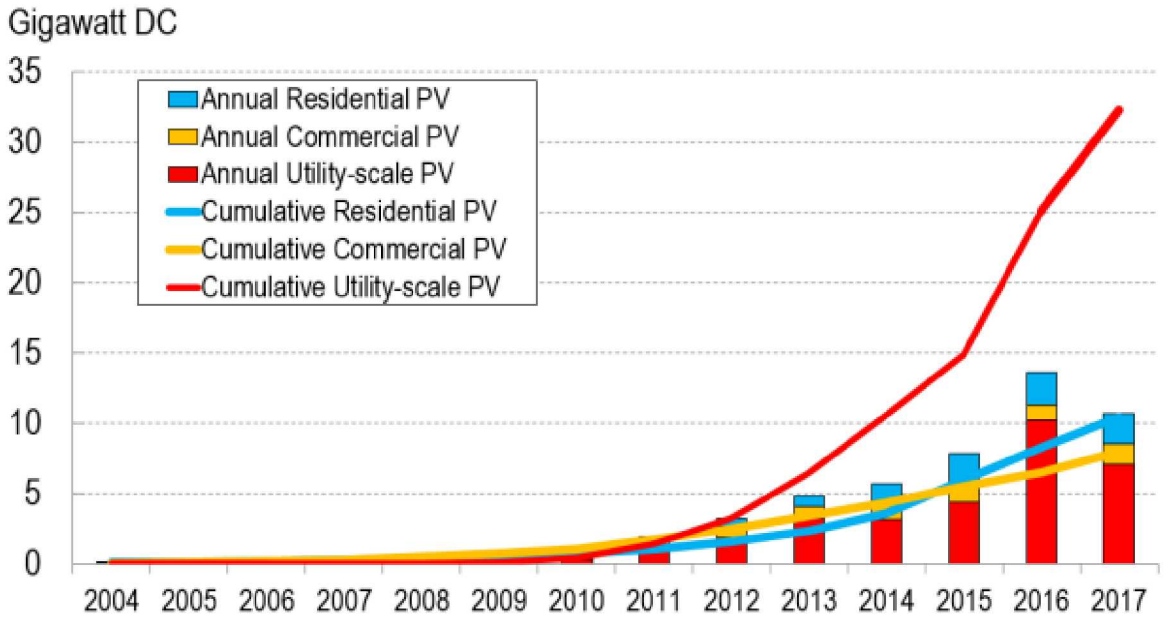


Figure 1. Growth of U.S. PV capacity, 2004–2017 (Bloomberg 2018)

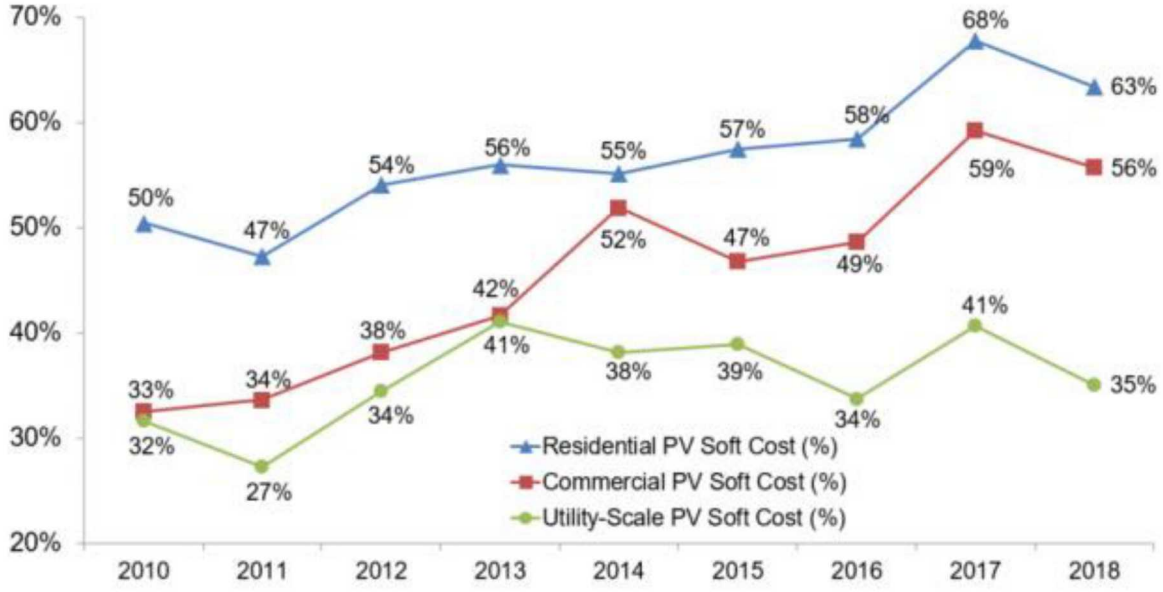


Figure ES-2. Modeled trend of soft cost as a proportion of total cost by sector, 2010–2018

- Relative increase in soft costs driven by decreasing hardware costs
- Also dealing with data management, PV aging process, …

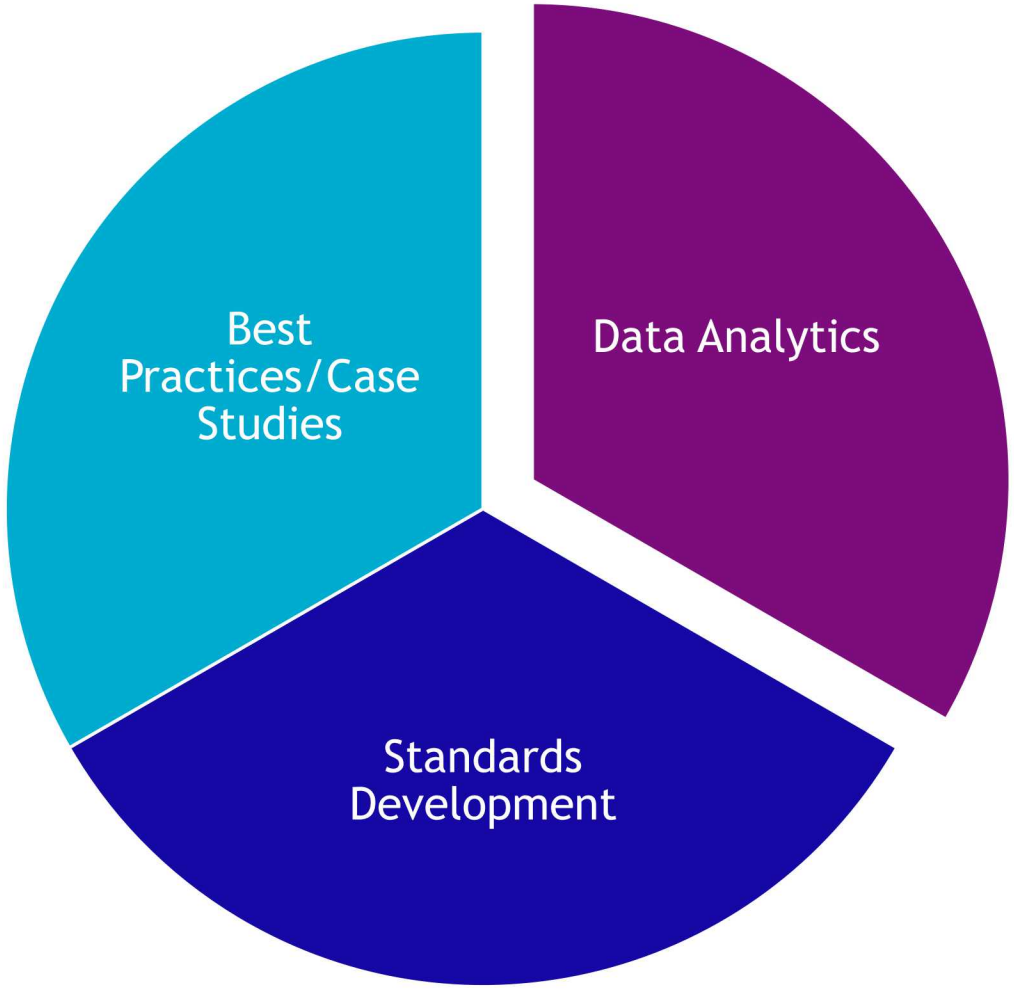
Source: https://www.nrel.gov/docs/fy19osti/72399.pdf

Critical Role of O&M

- O&M programs include
  - diagnosing and inspecting equipment,
  - identifying any necessary upgrades and
  - conducting repairs, and
  - continuously monitoring of all required systems.
- Effective O&M programs are often integrated into the overall program, and could influence administrative and engineering operations (e.g., identifying problematic hardware).
- These activities are critical for reducing unplanned shutdowns and maximize system operations…leading to lower life-cycle costs!

https://www.energy.gov/sites/prod/files/2013/10/f3/OM_3.pdf

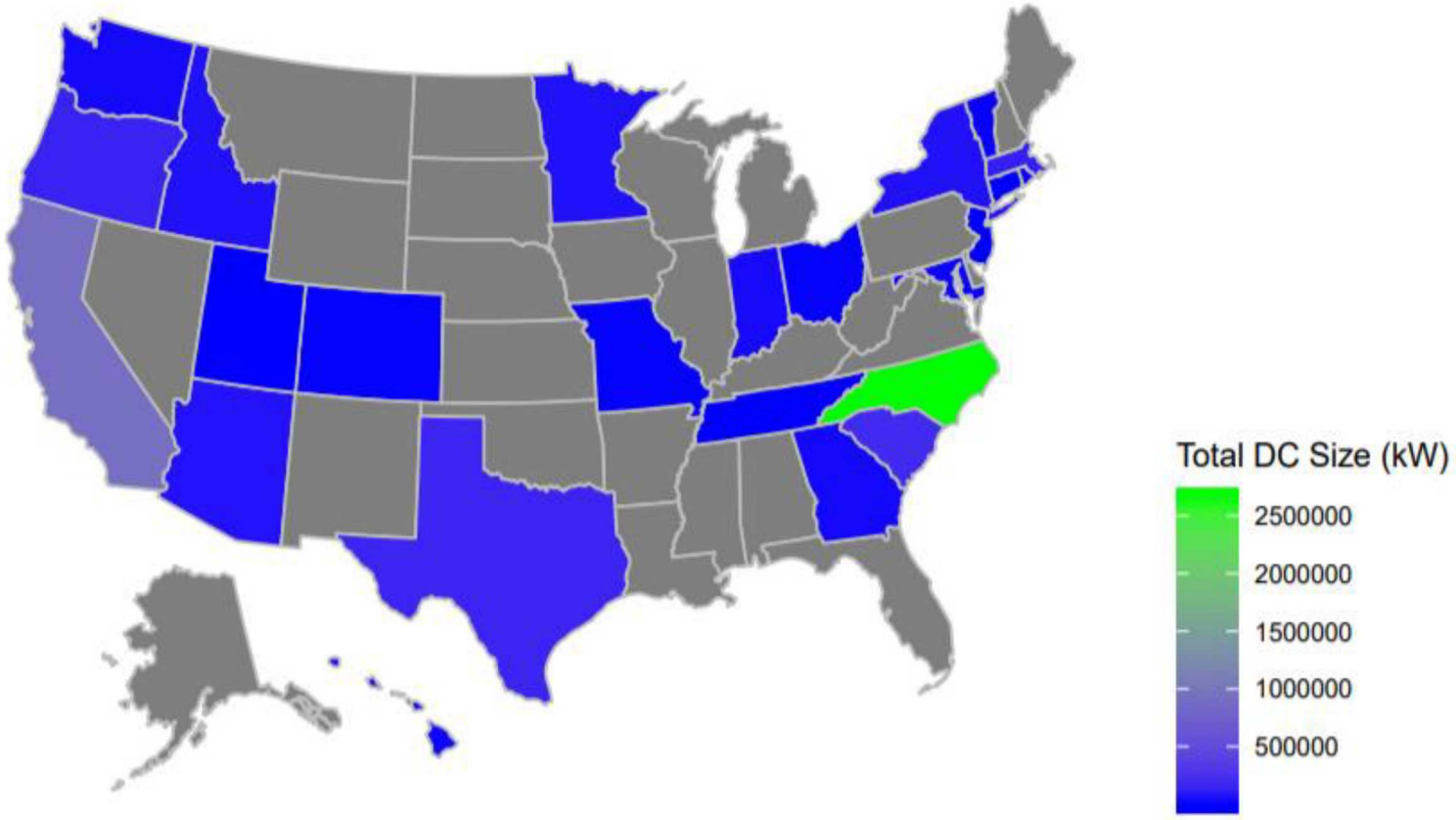
O&M Research Activities



PV Reliability Operations & Maintenance (PVROM) Database

- Sites capture O&M activities in CMMS
- Partner with industry to leverage empirical data to inform ongoing research activities and drive opportunities for reducing costs

	Current Database
Number of Industry Partners	5
Number of Sites (Utility Sites)	819 (529)
Total Sites DC Size (kW)	4,631,500
Total Sites AC Size (kW)	3,607,705
States Covered	24
NOAA Climate Regions	9
Köppen Climate Regions Covered	11
Oldest Commissioned Site	Jan 2008
Newest Commissioned Site	May 2019
Number of O&M Tickets	44,212



O&M Logs

Short descriptions of events are often captured

Provides valuable insight into details behind the incident as well as measures taken to address the observed issues

Data can be leveraged to understand patterns industry-wide

Incident Number	Incident Description	Corrective Action	Additional Comments	Occurred
VES12	Tilt sensor wire ripped on tracker controller #1.	Replaced with a new tilt sensor.		2/24/12 20:00
VES14	Broken module with impact hole in the middle of the module on tracker controller #9.	Replaced with a new module and scrapped the old one.	Impacted module replaced completely.	2/24/12 20:00
VES15	Controller #18 stuck east. Suspect PLC issue.	Replaced existing PLC not sending signal to VFD.		3/5/12 20:00

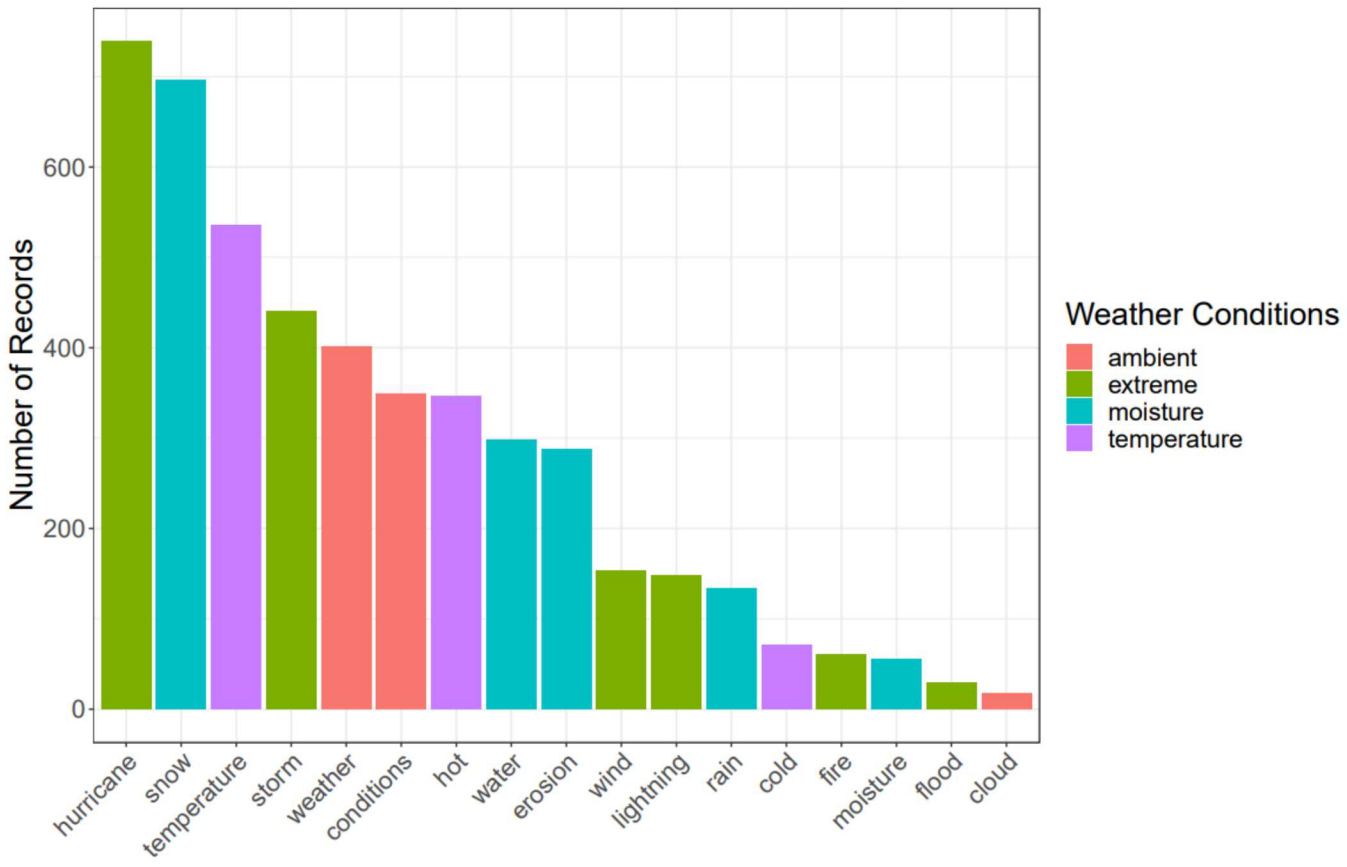
"All models are wrong, but some are useful"

- George P. Box

"All data are incomplete, but some are insightful…for answering a particular business question"*

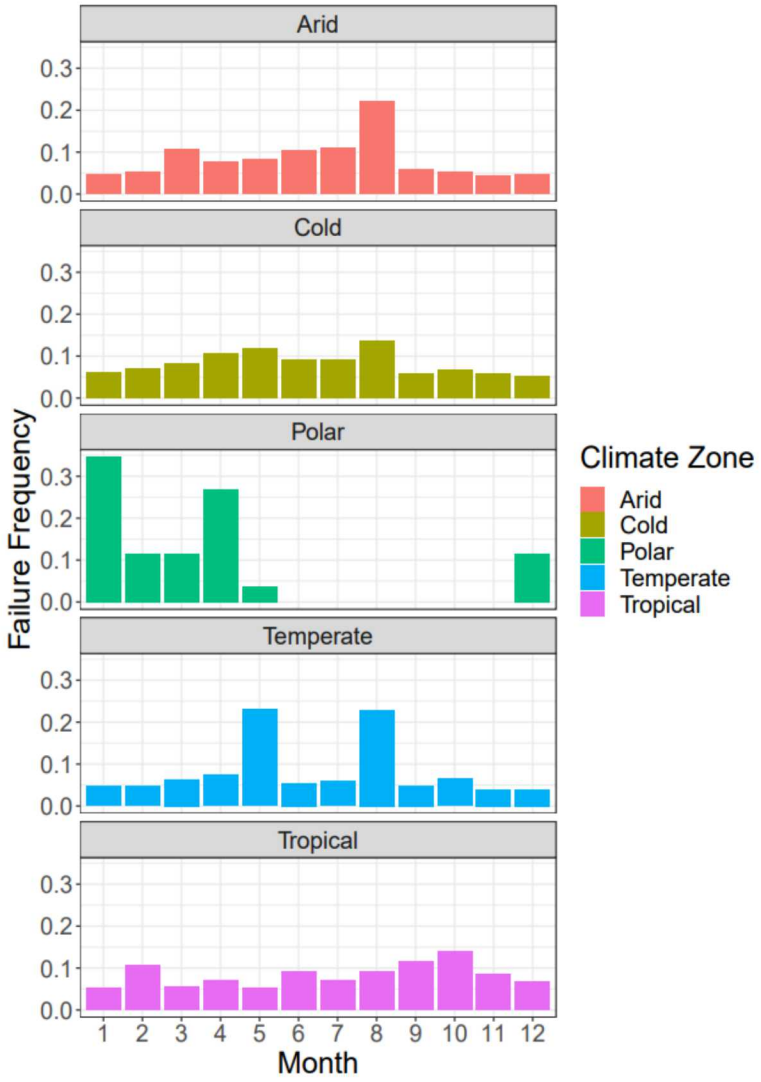
*many have voiced similar sentiments, including P.J. Diggle from Lancaster

Weather Impacts

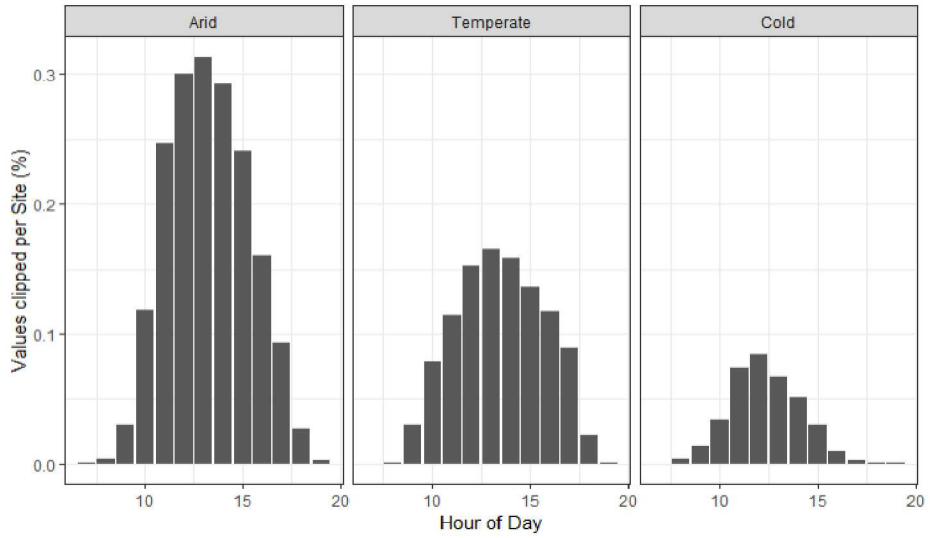


- Relevant tickets isolated through Key Term Identification (KTI), a Boolean logic approach that works well for unstructured data
- 12% of the PVROM records contain at least one weather term
- Both ambient and extreme weather conditions, including moisture and temperature conditions, dominate the database

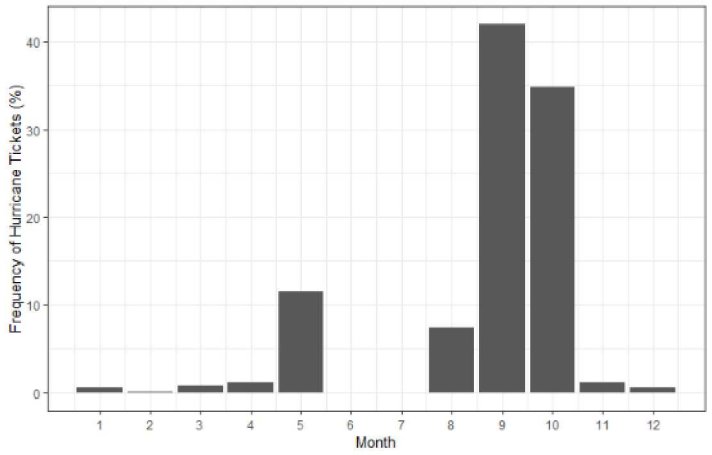
Ambient Weather Impacts

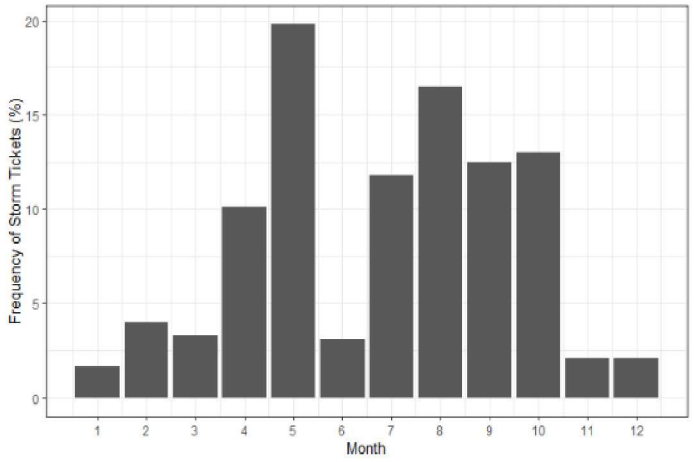


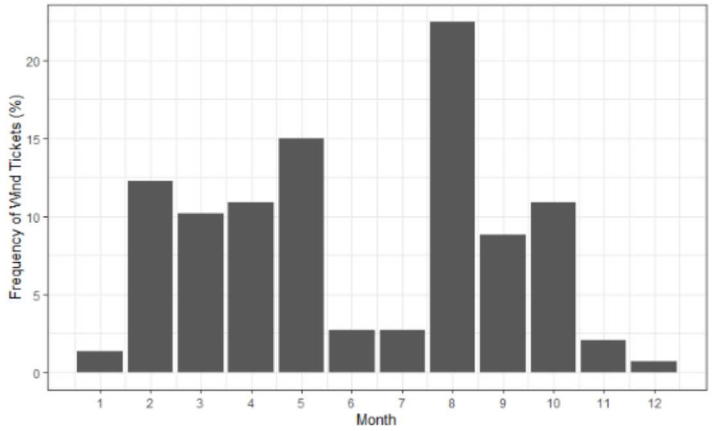
- Failure activities likely vary by climate region
  - Cold and tropical regionals have relatively constant failure rates over time
  - Temperature, arid, and polar regions have significantly more activity at certain times of the year
- Varying patterns in clipping frequencies are also present as a function of climate (arid >> cold)
- Ongoing analyses to identify specific equipment associated with these activities

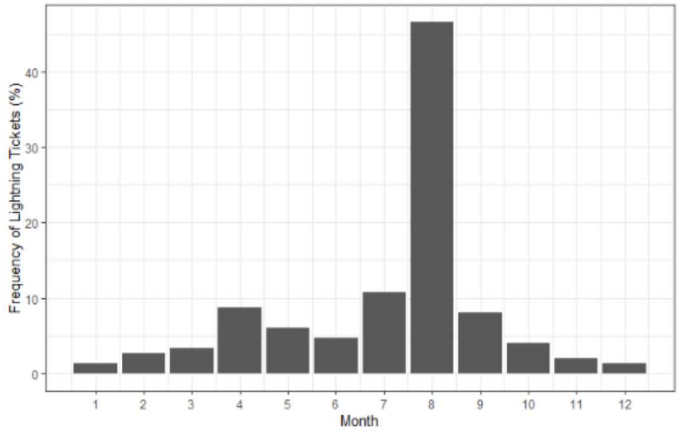


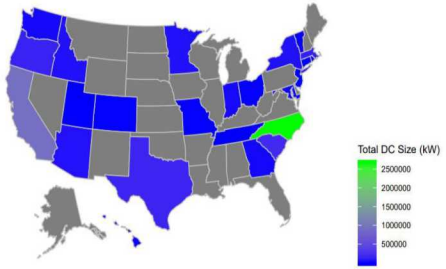
Extreme Weather Impacts





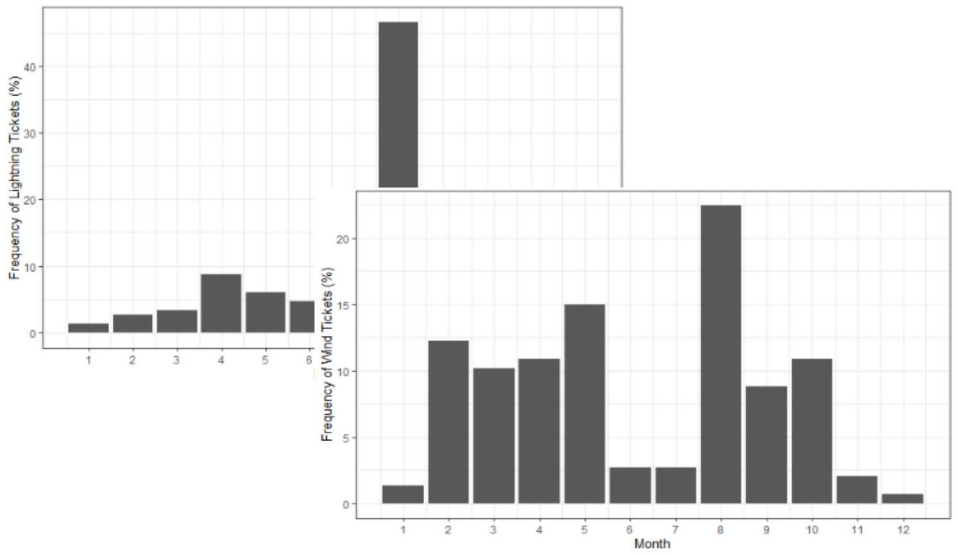




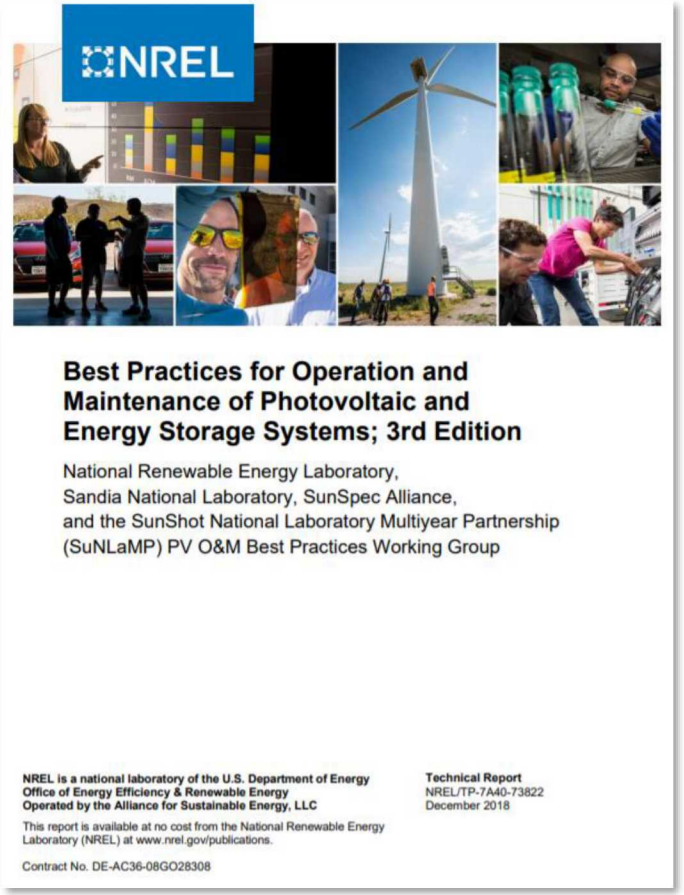


- Hurricanes mentioned more than storms (2x)
  - Unsurprising given PVROM's concentration in NC and SC
  - Tickets capture preventative maintenance, inspection post hurricane, and addressing hurricane-related damages
  - Generally, few details are captured. Often note: "hurricane-related inspection" or "hurricane-related. Site offline". So, there is a lot of room for improvement for capturing relevant details of interest
- Timing varies for weather impacts
  - Hurricanes: Sep and Oct
  - Storms: evenly spread throughout the year
  - Lightning: Aug
  - High winds: seasonal transition periods (between winter and spring and between summer and fall)
- Some events do use more than one weather term within the same entry but very uncommon (<5% storm tickets mention winds)

Informing Best Practices



- Characterize typical failures (e.g., trackers being stuck in wind stow mode)
- Improve planning activities: PM and expected rate of CM activities



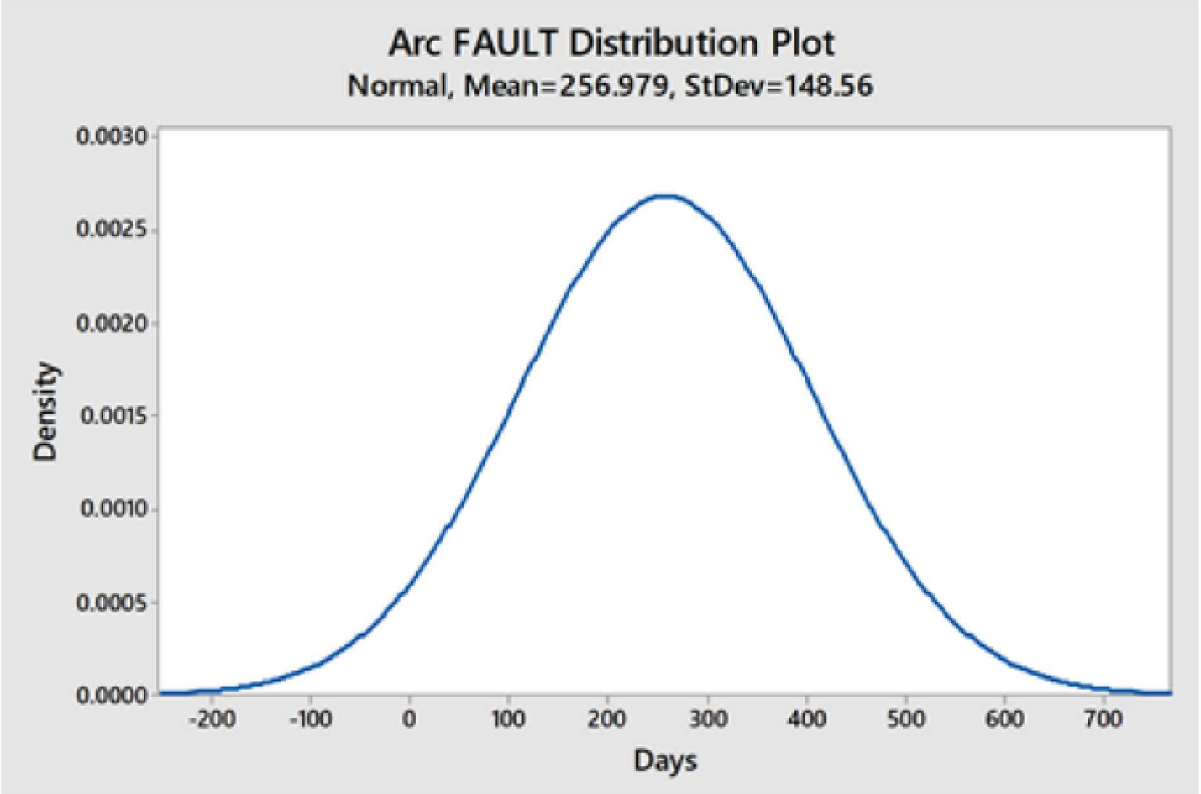
16K+ downloads!

https://www.nrel.gov/docs/fy19osti/73822.pdf

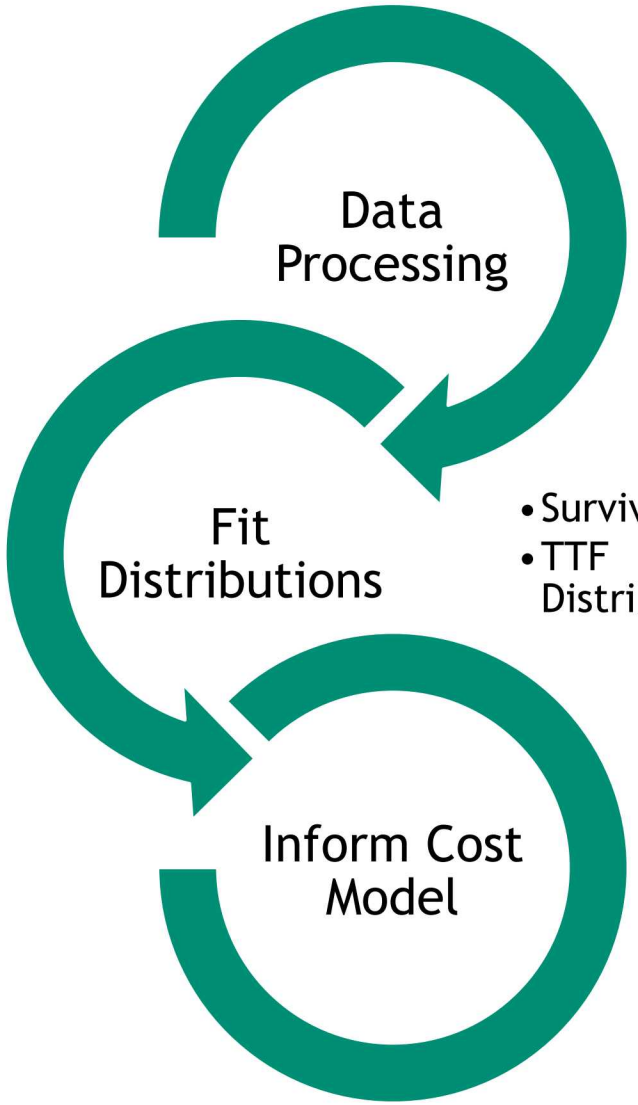
Failure Distributions

- Describe likelihood of an event (TTF, TTR, MTBF, etc.)
- Can calculate both
  - Distributions of likelihood across all sites (survival analysis)
  - Distributions of time to failure when it occurs
- Assumptions
  - Same root cause (aggregation)
  - Independent events
- Help characterize systemic issues in performance.
  - Infant mortality vs random
  - Lags between failures and response rates

Event	Inverter Commissioning Date	Downtime Start	Downtime End	TTF (days) = Downtime Start – Commissioning Date	TTR(days) = Downtime End – Downtime Start
Fan failure	6/15/2016 0:00	6/30/2016 14:05	7/1/2016 23:59	=6/30/2016 14:05 - 6/15/2016 0:00 = 15.586	= 7/1/2016 23:59 - 6/30/2016 14:05 = 1.412
Fan failure		7/13/2016 13:15	7/13/2016 15:05	=7/13/2016 13:15 - 6/15/2016 0:00 = 28.552	= 7/13/2016 15:05 - 7/13/2016 13:15 = 0.076



Improving O&M Cost Estimates

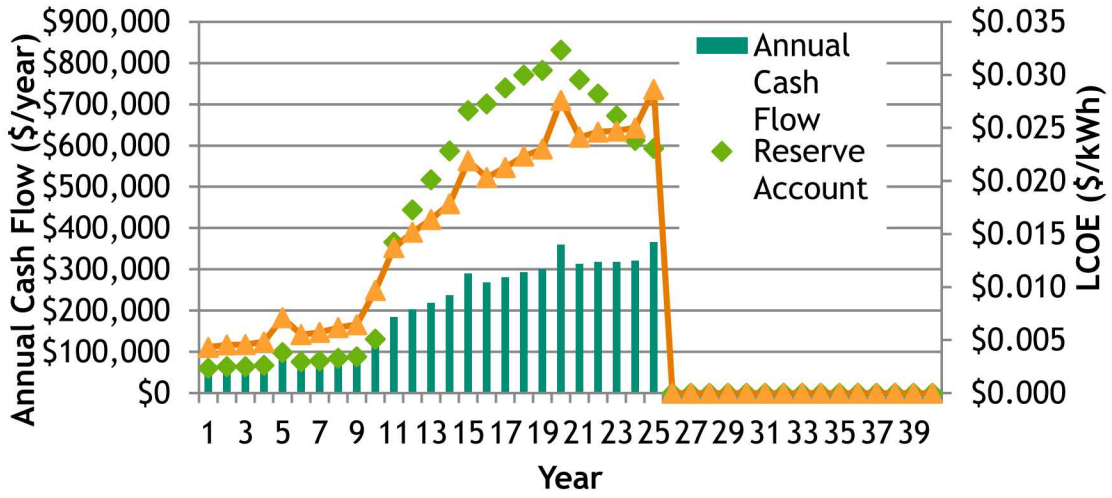


- Identify relevant records
- Calculate TTF

- Survival Analysis
- TTF Distributions

- Distribution type
- Distribution parameters

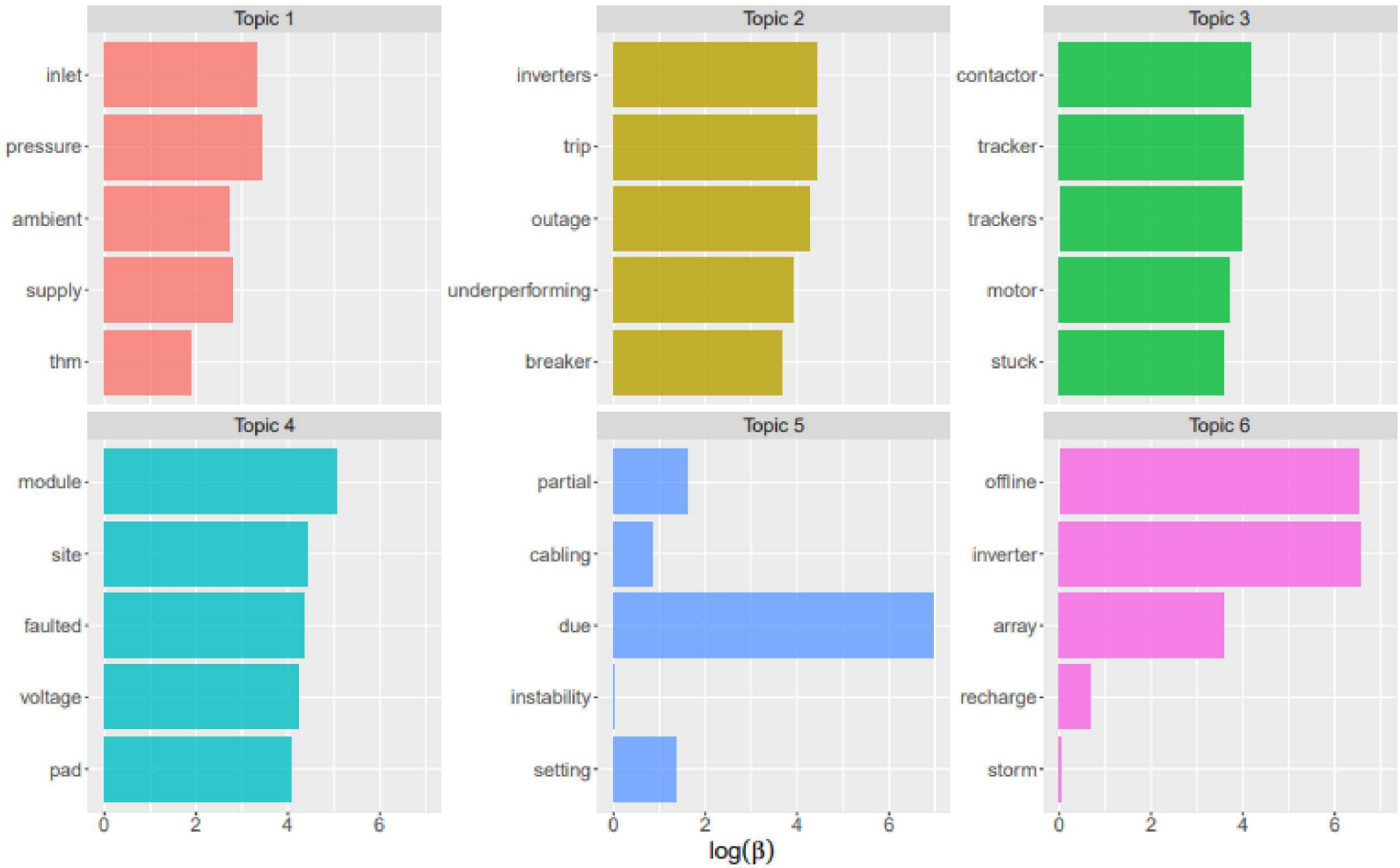
Activity Description
Replace protective devices (breakers) in building panel
Replace inverter AC fuse(s)
Locate line-to-line fault
Locate underground AC wiring
Repair line-to-line fault
Replace broken/crushed AC wiring conduit and fittings
Replace MC connector lead to combiner box
Replace MC Connectors between modules
Locate ground fault



PV O&M Cost Model. On-line version https://sunspec.org/wp-content/uploads/2016/03/SunSpecPVOMCostModelUserManual-Beta.pdf
Spreadsheet version by email andy.walker@nrel.gov www.nrel.gov/docs/fy17osti/68023.pdf

Common Failure Modes

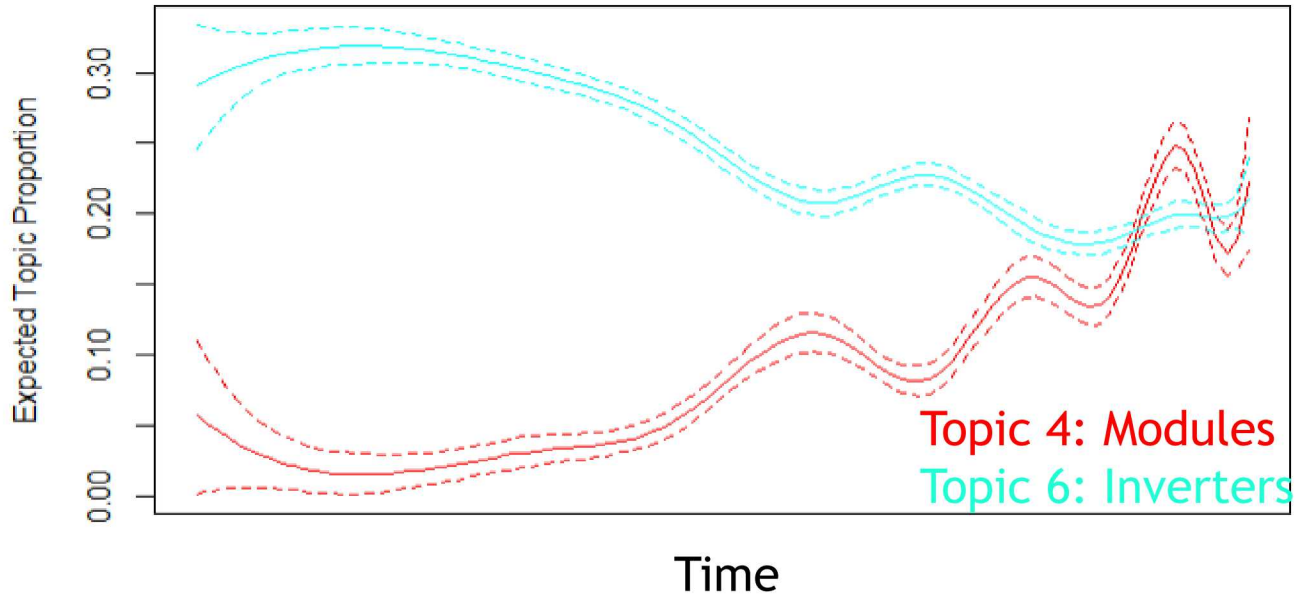
- Current failure modes identified by Subject Matter Expert (SME) input
- Could data help us understand
  - Relative occurrence?
  - Reveal additional failures?
- Use topic modeling to group co-occurring content
  - Lot more data processing is needed (ML to impose consistent structure)
  - Preliminary results for single partner on the right



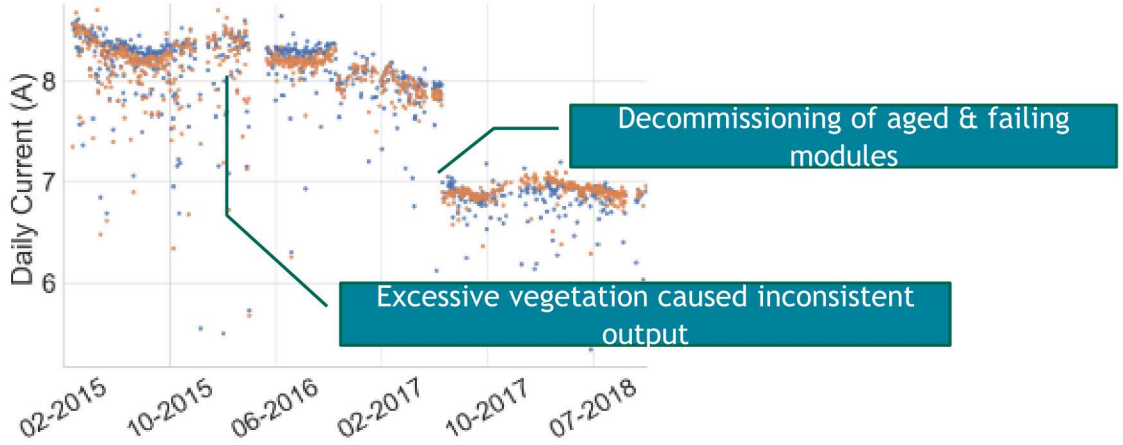
Grouping co-occurring content

Value of Findings

- More robust identification of failures (even if a particular word isn't mentioned)
  - Revisit cost model categories
  - Inform industry
- Inform data cleaning for degradation analyses
- …

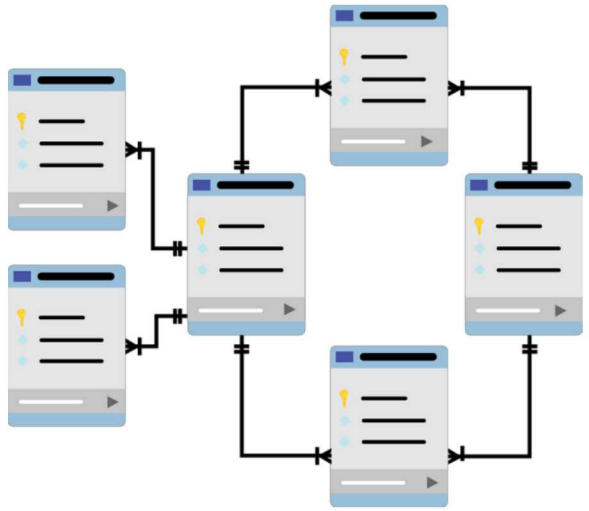


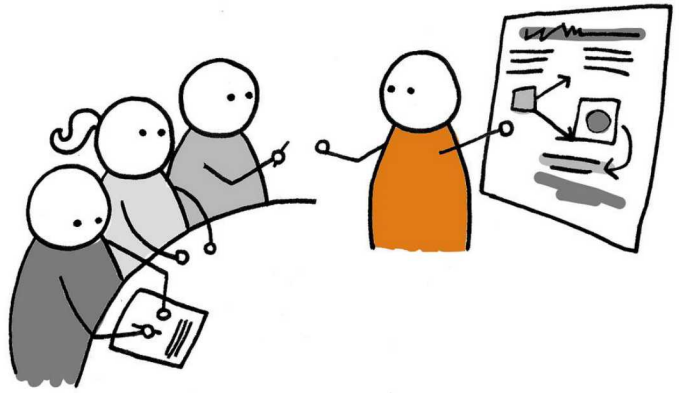
System Changes recorded in textual O&M records



Synergistic Activities: Improving Data Reusability

- Data Collection
  - Differences in available entries across platforms
  - Critical database elements
  - Technician Training
- Data Communication
  - OB Taxonomy
    - Relevant entries
    - Middleware
  - IEC Standards on Reliability



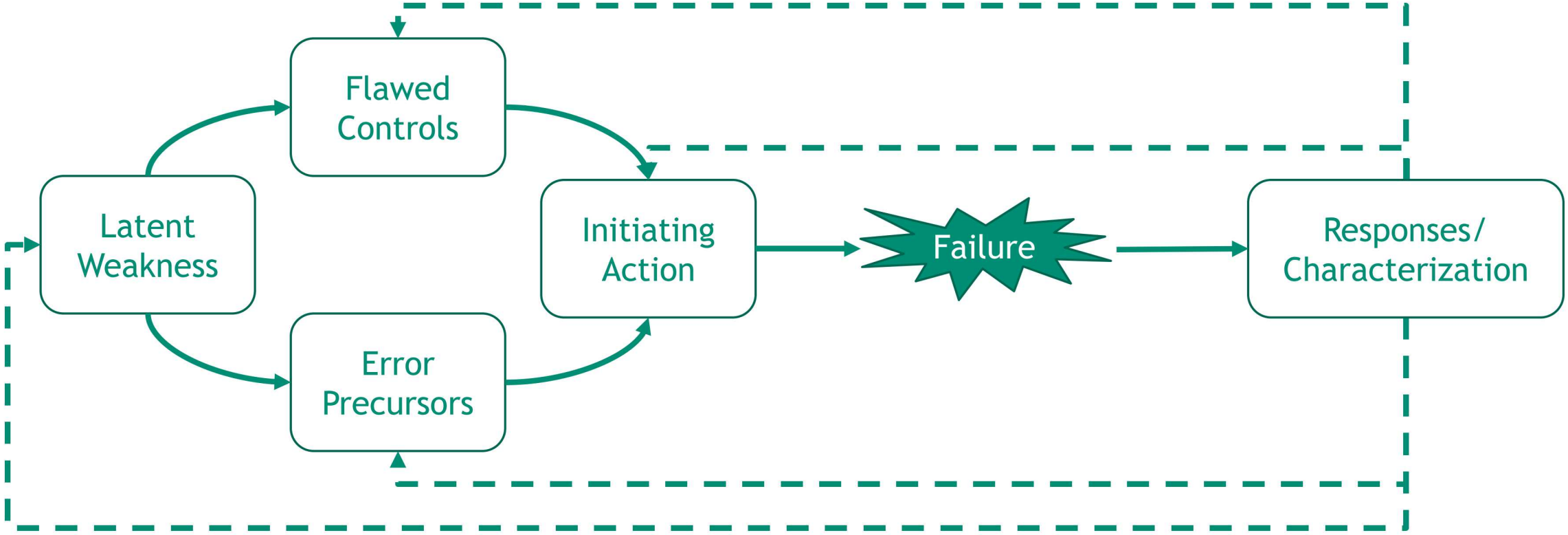


Orange Button℠

Standards Development | Solar Data Exchange

Evolving Process

- Feedback is appreciated
- Individual insights into O&M practices and larger system integration are valuable
- Always interested in more industry data



Thank you for your time!

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