

Reliability Analysis of Power Plant Unit Outage Problems

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Agenda

- What is our objective and why?
- What tools do we have available?
 - Reliable outage information
 - Measurements (statistics)
- How can we reach the objectives?
 - Unit-level benchmarking
 - Component-level benchmarking



What is Our Objective and Why?



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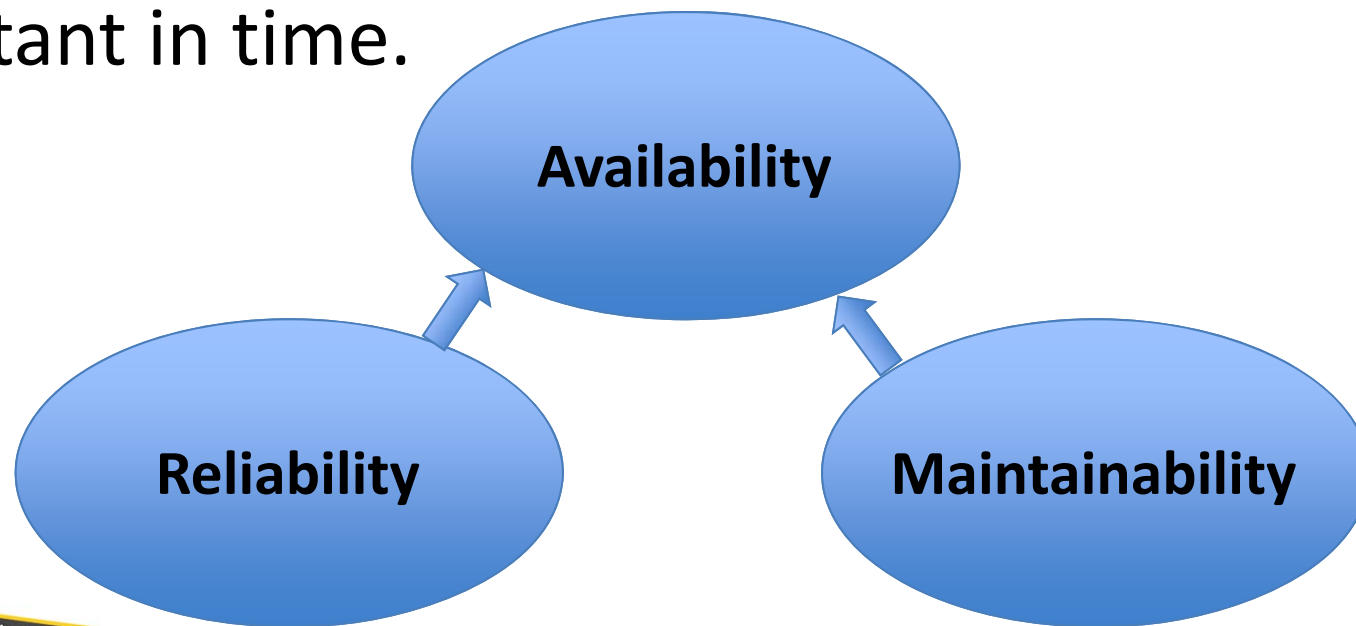
Definition

- **Reliability** is the characteristics of an item expressed as a probability that it will perform its required functions under specified conditions for a specified period of time.
- **Maintainability** is the characteristics of design and installation expressed as the probability that an item will be retained in or restored to a specified condition within a specified period of time when maintenance is performed in accordance with prescribed procedures and resources.



Definition

- **Availability** is the characteristic of an item expressed as a probability that it will be operational at a randomly selected future instant in time.



Game Plan

- To simply find ways that either outage frequency, outage duration, or both, can be reduced and kept at a level consistent with minimum generation costs and load management objectives.



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What Tools Do We Have Available?



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Reliability Databases

- Several databases to choose from:
 - Generating Availability Data System (GADS) – NERC
 - Operational Reliability Analysis Program (ORAP) - Strategic Power Systems, Inc.
 - KraftwerkInformationSSYstem (KISSY) - VGB of Essen, Germany
 - Power Reactor Information System (PRIS) - International Atomic Energy Agency (IAEA) of Austria
 - Canadian Electricity Association (CEA) – Ottawa, Canada



What is GADS?

- Generating Availability Data System (GADS)
 - Off shoot of the Edison Electric Institute database introduced in 1960's by the EEI Prime Movers Committee
 - GADS was introduced to the industry in 1982.
- Database for collecting and analyzing power plant equipment failures
 - Benchmarking
 - Setting realistic generating unit goals
 - Improving unit output and reliability
- Foundation for determining the reliability of the bulk power system as related to generating units



Why Mandatory GADS?

- When NERC became the Electric Reliability Organization (ERO) under the Energy Policy Act of 2005 (Section 215), it was given the mandate to monitor the reliability of the bulk power system:
 - Transmission
 - Generating facilities
 - Not distribution systems

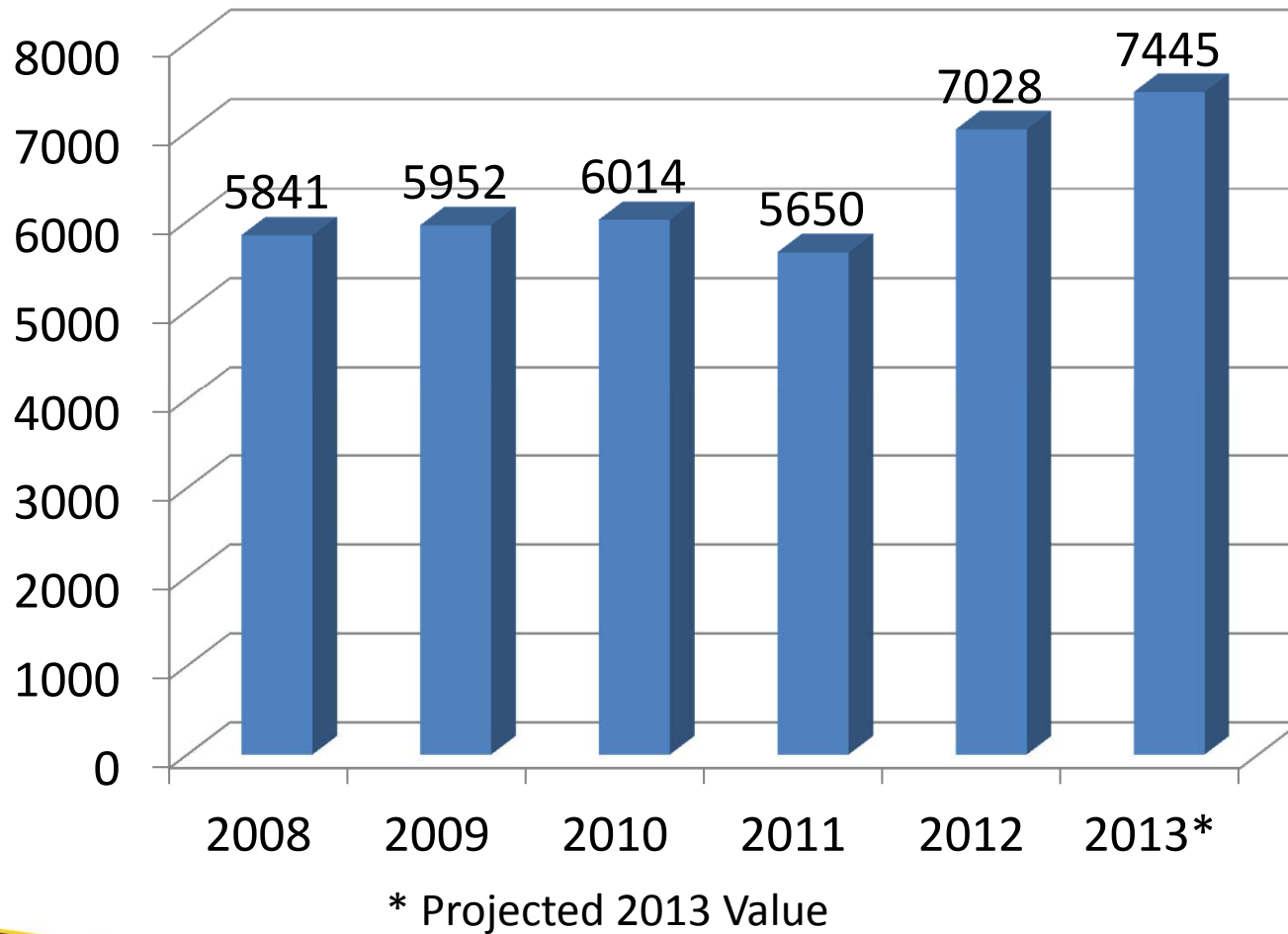


Why Mandatory GADS?

- Historically
 - Reliability assessment reports and modeling
 - Loss-of-load expectation studies and modeling
- New Challenges
 - As the resource mix changes, NERC and its stakeholders will need to understand how the changes in resource performance translates into Planning Reserve Margins.
 - Understanding the performance of existing and new resource technologies is essential to comprehending the reliability of the projected bulk power system in North America.

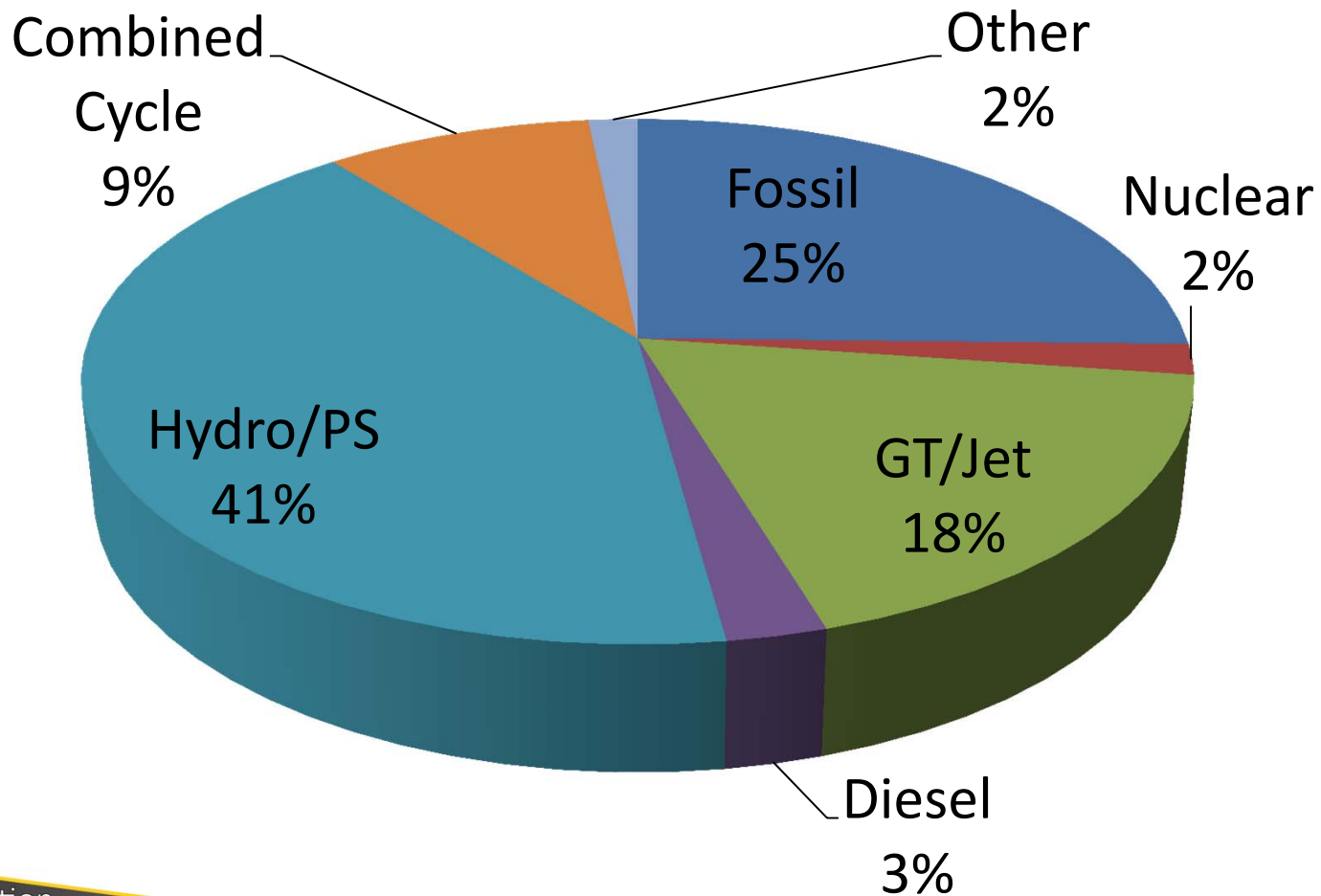


Generating Units Reporting to GADS



GADS Units by Unit Type

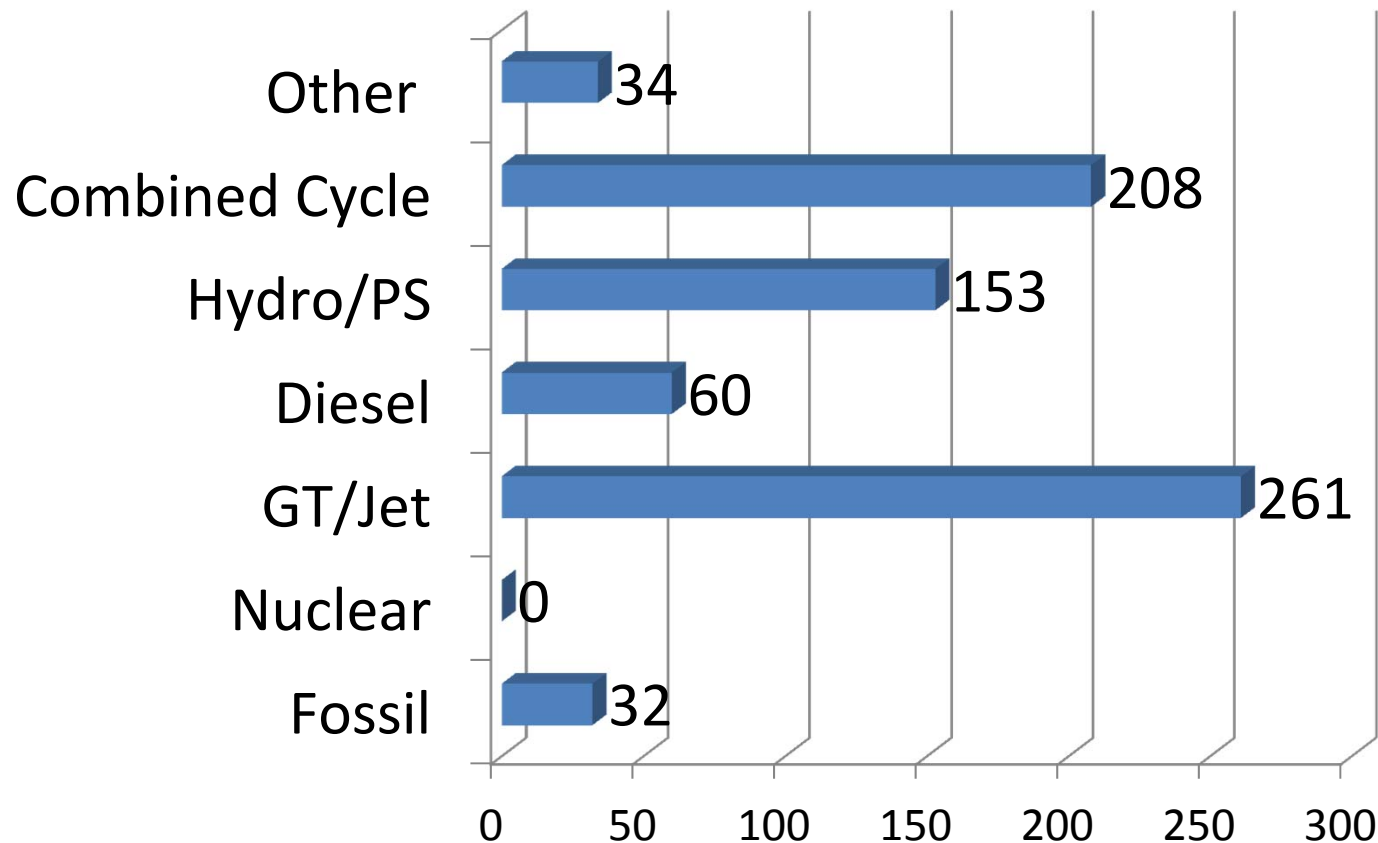
GADS 2012 Data



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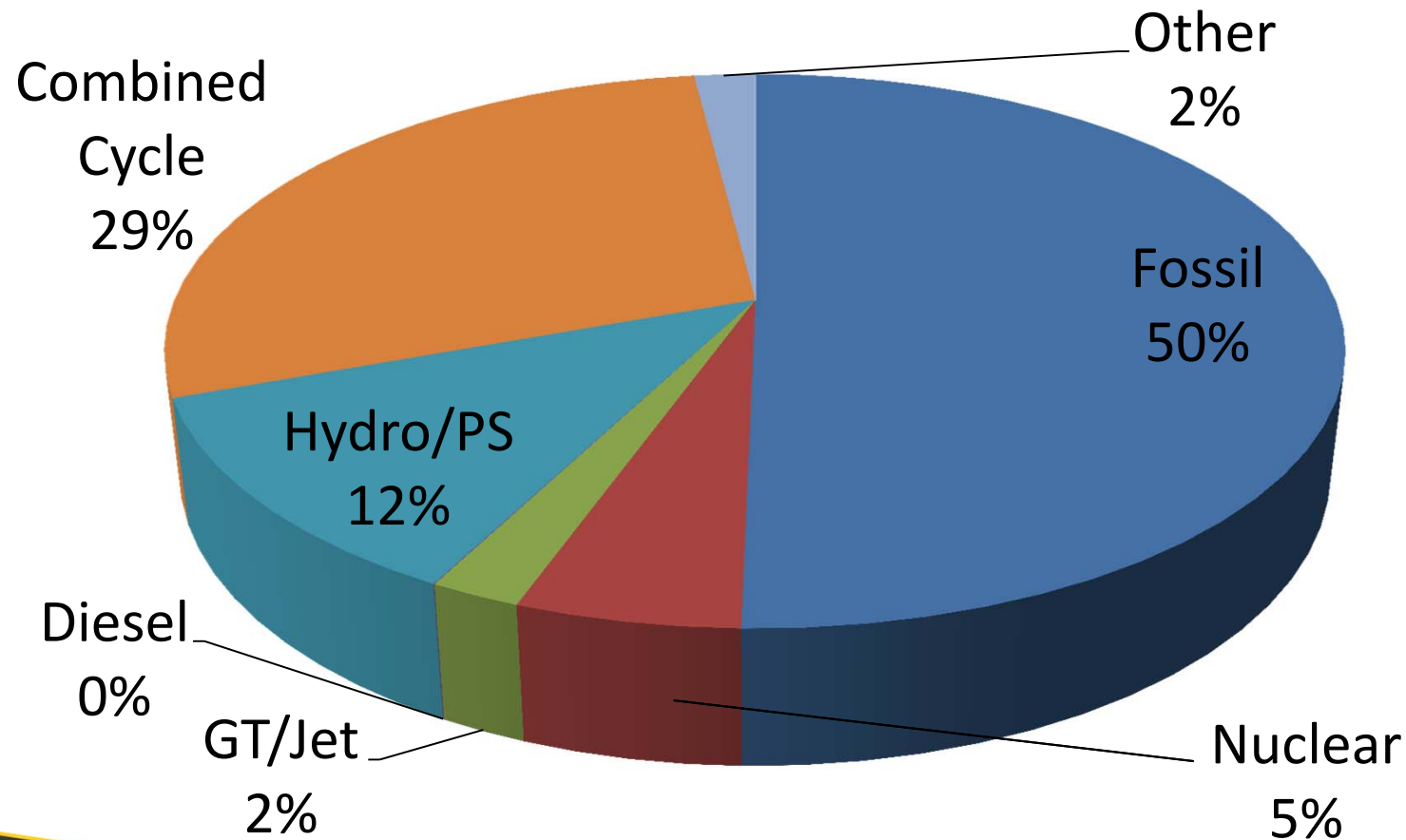
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New Construction 2004-2013



MW Generated

GADS 2012 Data



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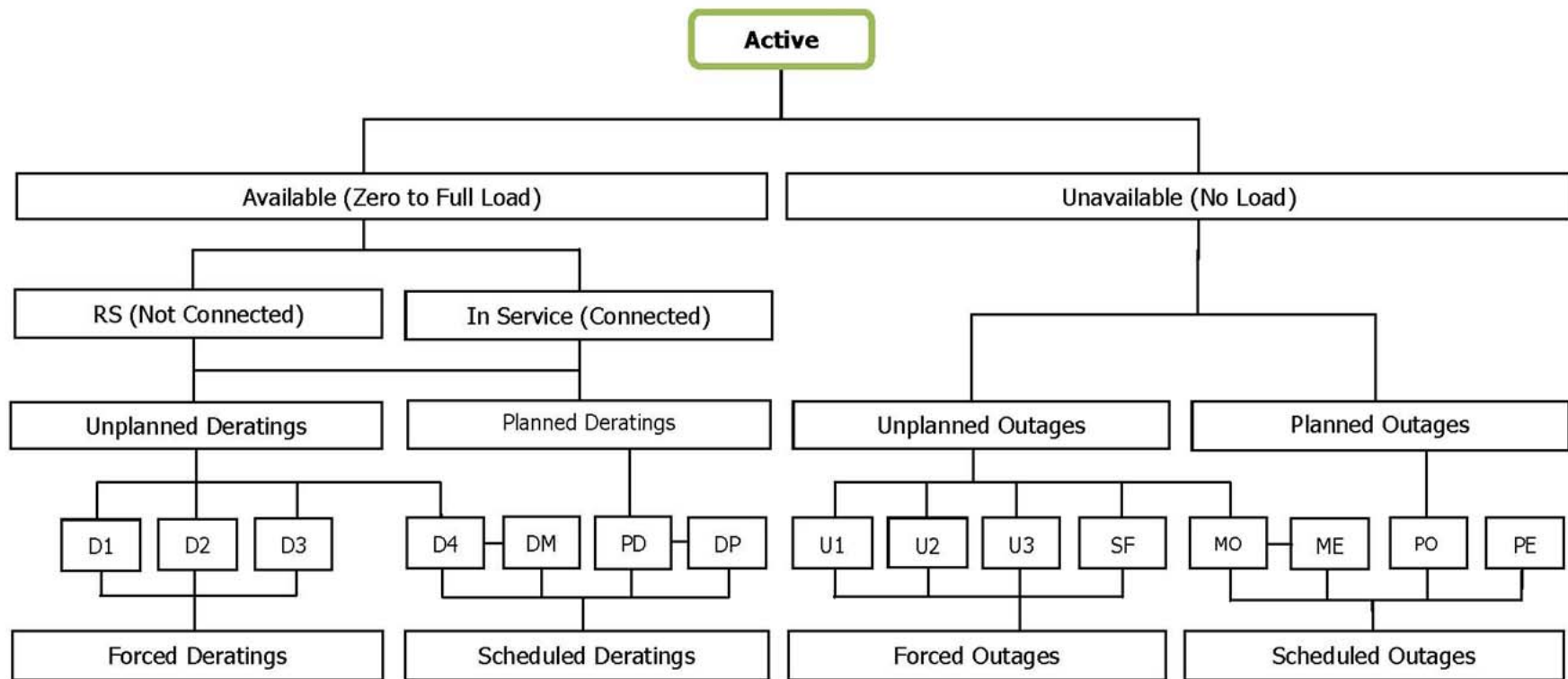
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What Data Does GADS Collect?

- Design data
 - Identify the various unit types
 - Separate units into groups by MW size, fuels, age, etc.
- Event data
 - Insights into equipment problems
 - Essential for evaluated unit designs such as pressurized verses balanced-draft furnaces
- Performance Data
 - Performance data provides information, in a summarized format, pertaining to overall unit operation during a particular month in a given year.



Unit State - Active



Details of reporting at GCS GADS Workshop. See handout.



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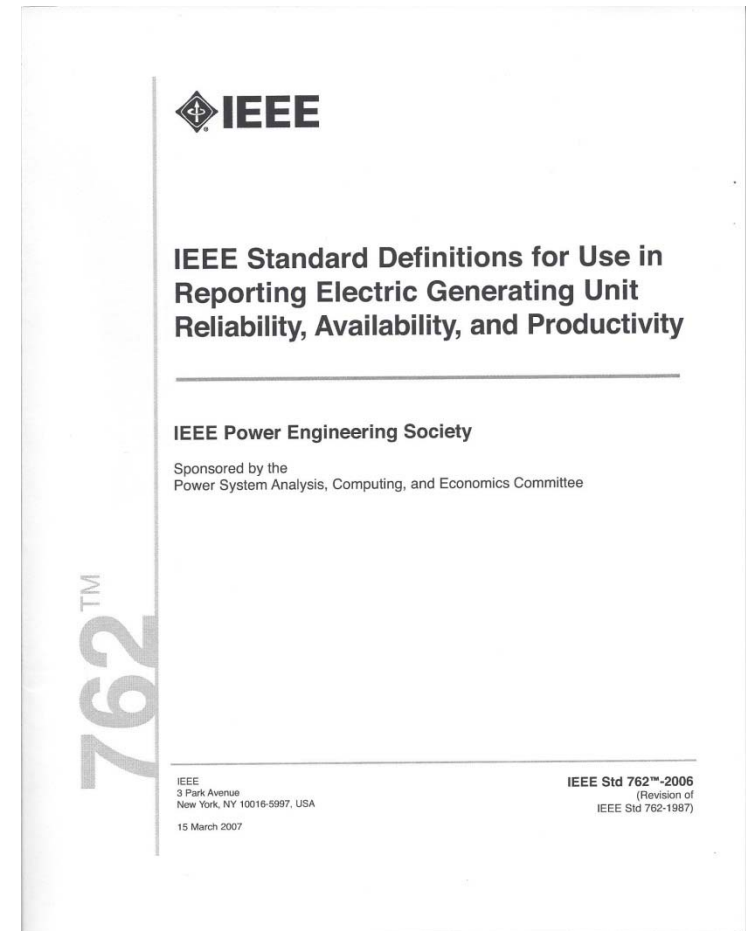
Primary Cause of Event

- GADS collects details regarding the system, major component, or piece of equipment primarily responsible for causing the outage or derating event.
- Primary details are required; secondary details are optional.
- **Important** details of event outage cause consists of:
 - System/Component cause codes (cause codes)
 - Cause Code Amplification Code (amp codes)
 - Event Contribution Code
 - Verbal Description



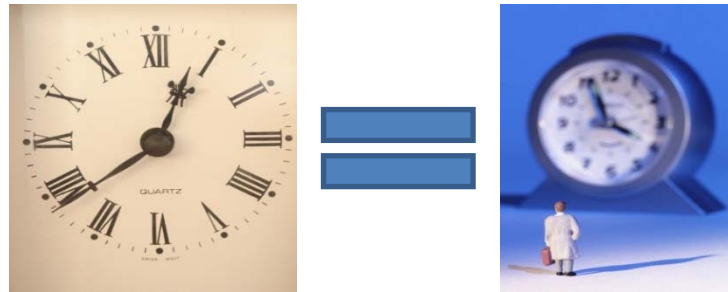
Basis of GADS Database

- IEEE 762 came from older Edison Electric Institute (EEI) documents developed during the 1970's.
- IEEE 762 was developed and tested in 1982; revised in 1987, 2006 and reaffirmed for 10 years in 2010.

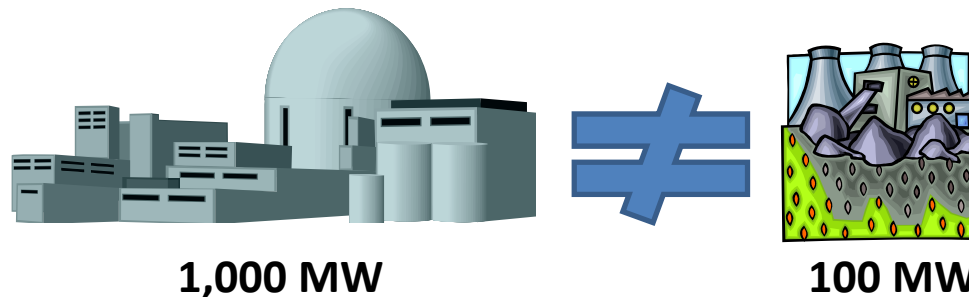


General Overview

- Un-weighted (time-based) – equations use time



- Weighted (energy or capacity based) – equations based on MW size of the units



IEEE 762 Indices – Factors

Discussion of the Most Common Uses IEEE 762 Factors and
Why They Are Important to the Power Industry



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Equivalent Availability Factor (EAF)

- *By Definition:*

- The fraction of net maximum generation that could be provided after all types of outages and deratings (including seasonal deratings) are taken into account.
- Measures percent of maximum generation available over time
- Not affected by load following
- The higher the EAF, the better
- Derates reduce EAF using Equivalent Derated Hours



The “E” in the Equation Name

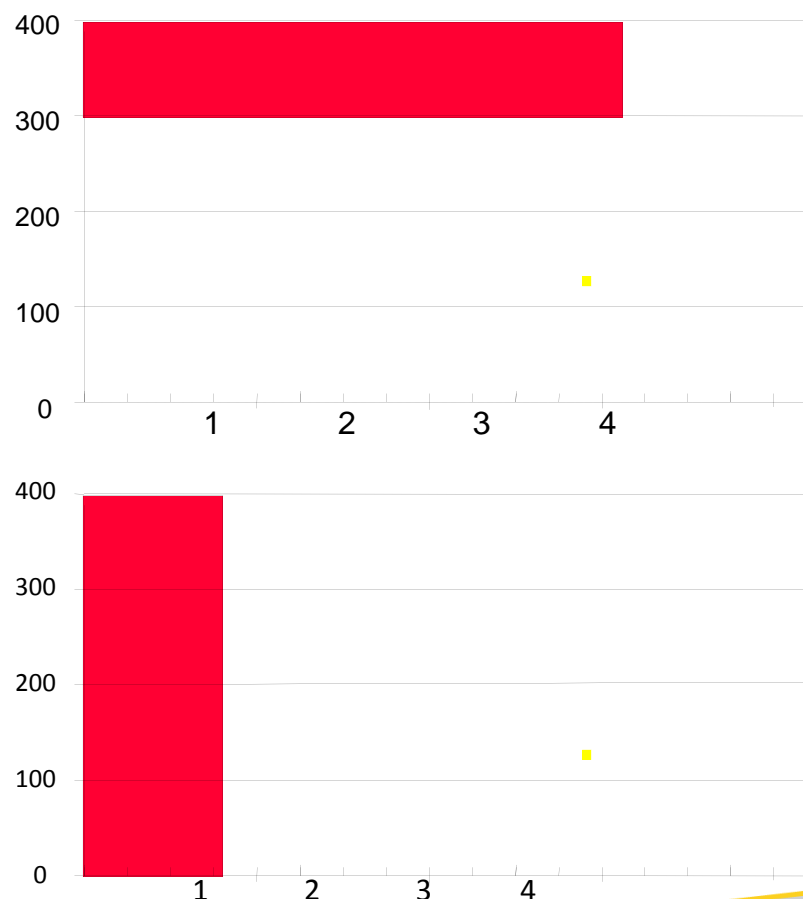
- When you see an “E” in the statistic’s name, it stands for “Equivalent” such as Equivalent Availability Factor (EAF) or Equivalent Forced Outage Rate – Demand (EFORd).
- These statistics contain deratings as well as full outages.
- Deratings only appear in GADS from event records, not performance records. So it is important to include all deratings in your reporting!



What are “Equivalent Derated Hrs.?”

- This is a method of converting deratings into full outages.
- The product of the Derated Hours and the size of reduction, divided by NMC.
- 100 MW derate for 4 hours is the same loss as 400 MW outage for 1 hour.

$$100\text{MW} \times 4\text{hours} = 400\text{MW} \times 1\text{hour}$$



Scheduled Outage Factor (SOF)

- *By Definition:*
 - The percent of time during a specific period that a unit is out of service due to either planned or maintenance outages.
 - Outages are scheduled.
 - PO – “Well in Advance”
 - MO - Beyond the next weekend
 - A measure of the unit’s unavailability due to planned or maintenance outages.
 - The lower the SOF, the better.



Net Capacity Factor (NCF)

- *By Definition:*
 - Measures the actual energy generated as a fraction of the maximum possible energy it could have generated at maximum operating capacity.
 - Shows how much the unit was used over the period of time
 - The energy produced may be outside the operator's control due to dispatch.
 - The higher the NCF, the more the unit was used to generate power (moving to “base-load”).



Net Output Factor (NOF)

- *By Definition:*
 - Measures the output of a generating unit as a function of the number of hours it was in service (synchronized to the grid).
 - How “hard” was the unit pushed
 - The energy produced may be outside the operator’s control due to dispatch.
 - The higher the NOF, the higher the loading of the unit when on-line.



Comparing NCF and NOF

$$\text{NCF} = \frac{100\% \times (\text{Net Actual Generation})}{[\text{PH} \times (\text{Net Maximum Capacity})]}$$

$$\text{NOF} = \frac{100\% \times (\text{Net Actual Generation})}{[\text{SH} \times (\text{Net Maximum Capacity})]}$$

NCF measures % of time at full load.

NOF measures the loading of the unit when operated.



What can you learn from this chart?

	EAF	NCF	NOF
Nuclear	87.19	88.36	98.96
Fossil, coal	83.33	63.62	81.15
Fossil, gas	84.17	12.53	35.98
Fossil, oil	83.83	8.12	39.81
Gas turbines	88.54	2.51	69.69
Hydro	84.61	40.67	67.43

(Data from the 2008-2012 GADS Brochure)



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IEEE 762 Equations – Rates

Discussion of the Most Common Uses IEEE 762 Rates and
Why They Are Important to the Power Industry



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Forced Outage Rate

- *By Definition:*
 - The percent of scheduled operating time that a unit is out of service due to unexpected problems or failures.
 - Measures the reliability of a unit during scheduled operation
 - Sensitive to service time
 - (reserve shutdowns and scheduled outages influence FOR results)
 - Best used to compare similar loads:
 - base load vs. base load
 - cycling vs. cycling
 - The lower the FOR, the better.



Forced Outage Rate

Calculation:

$$\text{FOR} = \left[\frac{\text{FOH}}{\text{FOH} + \text{SH} + \text{Syn Hrs.} + \text{Pmp Hrs.}} \right] \times 100\%$$

Comparison: unit with high SH vs. low SH
(SH = 6000 hrs. vs. 600 hrs.; FOH = 200 hrs.)

$$\text{FOR} = \frac{200}{200 + 6000} = 3.23\%$$

$$\text{FOR} = \frac{200}{200 + 600} = 25.00\%$$



Equivalent Forced Outage Rate

- *By Definition:*
 - The percent of scheduled operating time that a unit is out of service due to unexpected problems or failures AND cannot reach full capability due to forced component or equipment failures.
 - The probability that a unit will not meet its demanded generation requirements.
 - Good measure of reliability
 - The lower the EFOR, the better.



Equivalent Forced Outage Rate

Calculation:

$$\text{EFOR} = \frac{\text{FOH} + \text{EFDH}}{(\text{FOH} + \text{SH} + \text{Syn Hrs.} + \text{Pmp Hrs.} + \text{EFDHRS})}$$

where $\text{EFDH} = (\text{EFDHSH} + \text{EFDHRS})$

EFDHSH is Equivalent Forced Derated Hours during Service Hours.

EFDHRS is Equivalent Forced Derated Hours during Reserve Shutdown Hours.



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Equivalent Forced Outage Rate

As an example:

FOH = 750, EFDH = 450, SH = 6482, EDFHRS=0,
Syn Hrs. = 0, Pmp Hrs. = 0

$$EFOR = \frac{FOH + EFDH}{(FOH + SH + EDFHRS)}$$

$$EFOR = \frac{750 + 450}{(750 + 6482 + 0)} = 16.6\%$$



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Equivalent Forced Outage Rate – Demand (EFORd)

- Markov equation developed in the 1970's
- Used by the industry for many years
 - PJM Interconnection
 - Similar to that used by the Canadian Electricity Association
 - Being use by the CEA, PJM, New York ISO, ISO New England, and California ISO

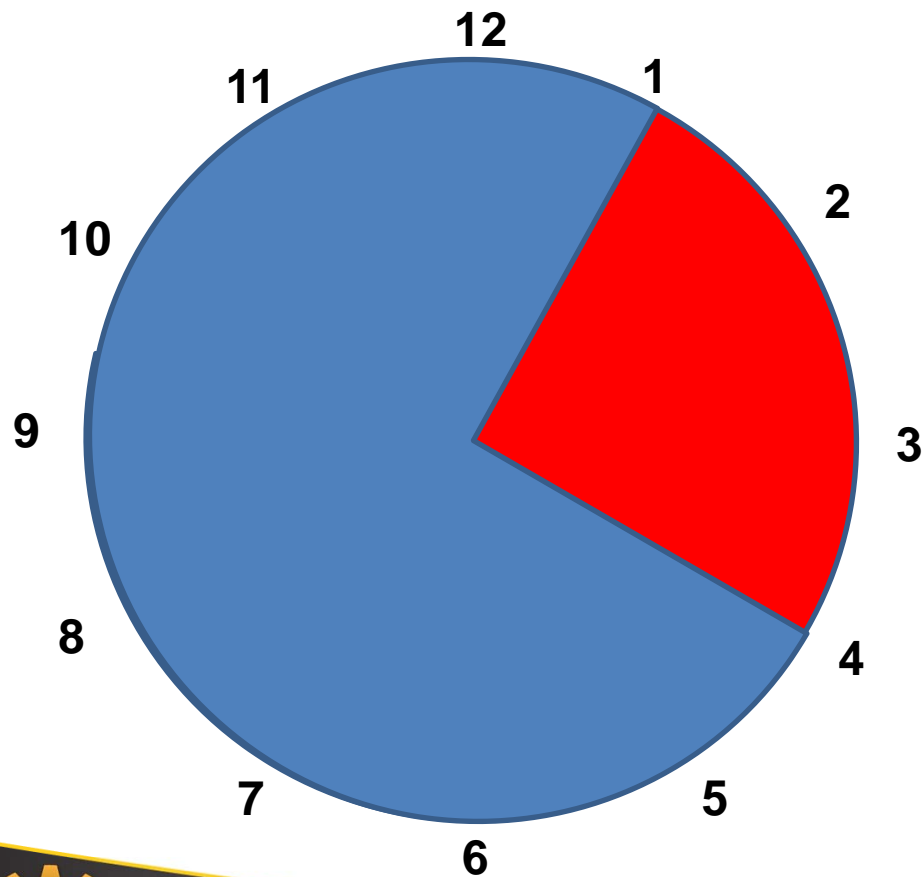


Equivalent Forced Outage Rate – Demand (EFORd)

- Interpretation:
 - The probability that a unit will not meet its demand periods for generating requirements.
 - Best measure of reliability for all loading types (base, cycling, peaking, etc.)
 - Best measure of reliability for all unit types (fossil, nuclear, gas turbines, diesels, etc.)
 - For demand period measures and not for the full 24-hour clock.
 - The lower the EFORd, the better.



Equivalent Forced Outage Rate – Demand (EFORd)



EFORd will allow you to measure the probability of a forced event during demand times. In this example, between 1 & 4 pm.



EFORd Equation:

$$\text{EFORd} = \frac{[(\text{FOHd}) + (\text{EFDHd})]}{[\text{SH} + (\text{FOHd})]} \times 100\%$$

Where: $\text{FOHd} = f \times \text{FOH}$

$$f = \frac{[(1/r) + (1/T)]}{[(1/r) + (1/T) + (1/D)]}$$

$r = \text{FOH} / (\# \text{ of FOH occur.})$

$T = \text{RSH} / (\# \text{ of attempted Starts})$

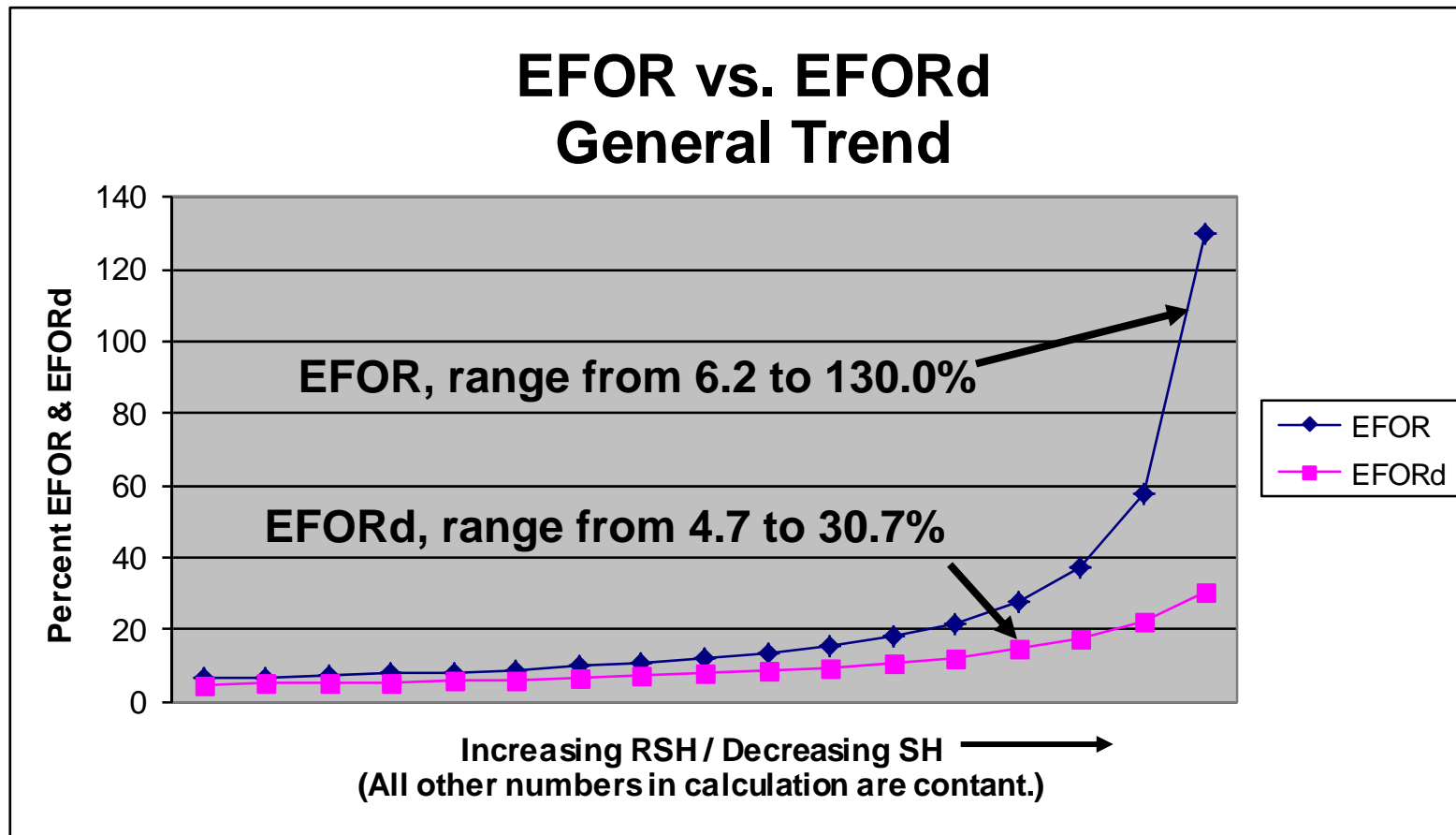
$D = \text{SH} / (\# \text{ of actual starts})$

$\text{EFDHd} = f_p \times \text{EFDH}$

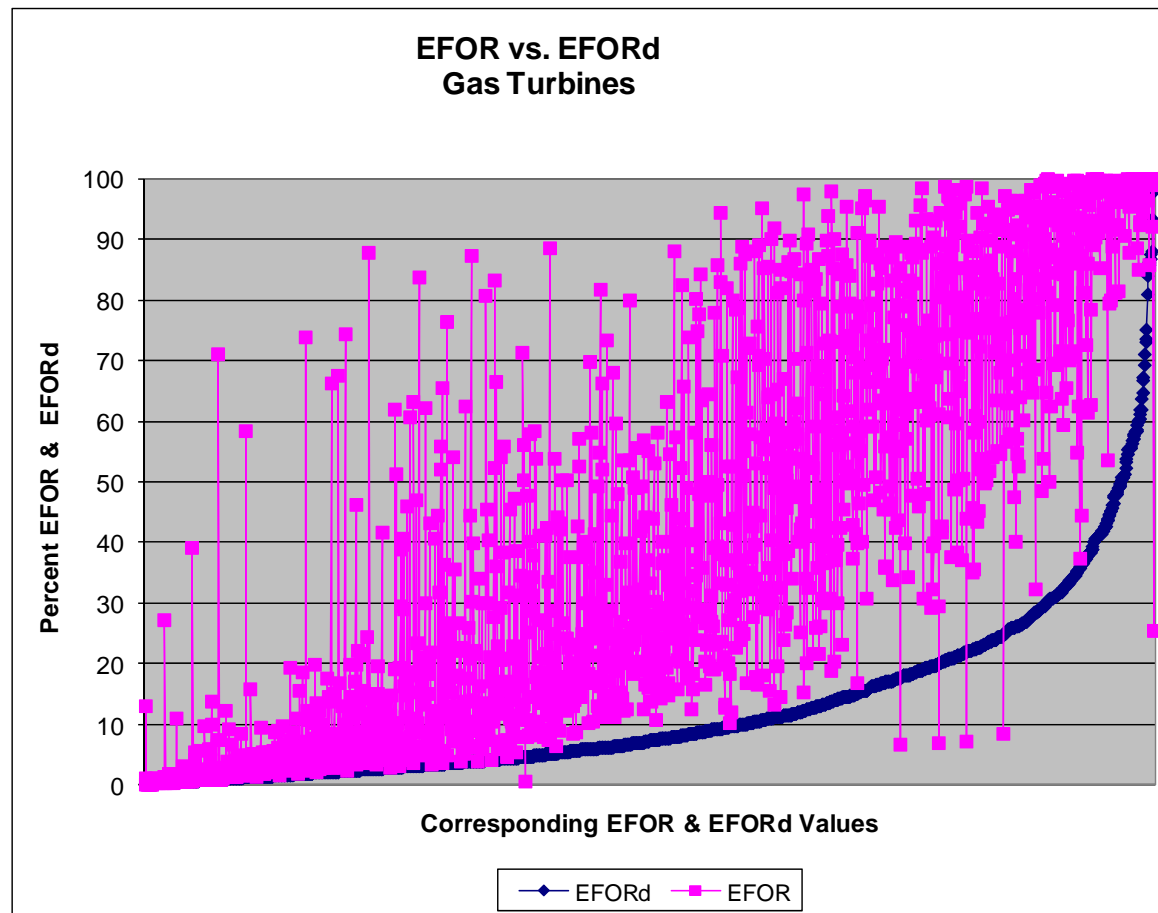
$f_p = \text{SH} / \text{AH}$



Example of EFORd vs. EFOR



Example of EFORd vs. EFOR



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What can you learn from this chart?

	FOR	EFOR	EFORd	SH	RSH
Nuclear	3.34	3.94	3.94	7,788.59	1.67
Fossil, coal	6.12	8.30	7.52	6,150.41	1,265.64
Fossil, gas	14.41	16.64	9.68	2,358.66	4,459.50
Fossil, oil	15.23	17.31	12.71	1,810.89	5,432.38
Gas turbines	63.09	62.79	10.65	208.89	7,693.79
Hydro	5.79	5.99	5.43	5,226.12	1,532.32

(Data from the 2008-2012 GADS Brochure)



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EAFF + EFOR = 100%?

Given: PH = 8760, SH = 10, RSH = 8460. FOH = 290. No deratings.

$$EAF = AF = \frac{AH}{PH}$$

$$EFOR = FOR = \frac{FOH}{(SH + FOH)}$$

$$EAF = \frac{8470}{8760}$$

$$EFOR = \frac{290}{(290 + 10)}$$

$$EAF = 97.7\%$$

$$EFOR = 97.7\%$$

Factors and rates are not additive
and not complementary!



Outside Management Control (OMC)

- There are a number of outage causes that may prevent the energy coming from a power generating plant from reaching the customer. Some causes are due to the plant operation and equipment while others are outside plant management control (OMC).
- GADS needs to track all outages but wants to give some credit for OMC events.



What are OMC Events?

- Grid connection or substation failure
- Acts of nature such as ice storms, tornados, winds, lightning, etc.
- Acts of terrors or transmission operating/repair errors
- Lack of fuels
 - Water from rivers or lakes, coal mines, gas lines, etc.
 - BUT NOT operator elected to contract for fuels where the fuel (for example, natural gas) can be interrupted
- Labor strikes
 - BUT NOT direct plant management grievances



Comparing EAF, WEAF, XEAF, etc.

$$\text{EAF} = \frac{(\text{AH} - \text{ESDH} - \text{EFDH} - \text{ESEDH})}{\text{PH}} \times 100\%$$

$$\text{WEAF} = \frac{\sum \text{NMC}(\text{AH} - \text{ESDH} - \text{EFDH} - \text{ESEDH})}{\sum \text{NMC}(\text{PH})} \times 100\%$$

$$\text{XEAF} = \frac{(\text{AH} - \text{ESDH} - \text{EFDH} - \text{ESEDH})}{\text{PH}} \times 100\%$$

$$\text{XWEAF} = \frac{\sum \text{NMC}(\text{AH} - \text{ESDH} - \text{EFDH} - \text{ESEDH})}{\sum \text{NMC}(\text{PH})} \times 100\%$$



Comparing EAF, WEOF, XEAF, etc.

	Fossil (All sizes), Coal	Nuclear	Gas Turbines
EAF	84.64%	86.15%	90.28%
WEOF	84.25%	86.64%	90.06%
XEAF	85.21%	86.50%	90.76%
XWEOF	84.74%	86.98%	90.56%



How Can We Reach the Objectives?



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What Is Benchmarking?

- BusinessDictionary.com defines it as
 - A measurement of the quality of an organization's policies, products, programs, strategies, etc., and their comparison with standard measurements, or similar measurements of **its peers**.
 - The objectives of benchmarking are: (1) to determine what and where improvements are called for; (2) to analyze how other organizations achieve their high performance levels; and (3) to use this information to improve performance.



Modes of Transportation



There are different ways to travel. In benchmarking, there are different ways to determine peer groups and compare your generating units.



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Why Benchmark?

- Benchmarking is helping utilities
 - Set goals
 - Develop incentives
 - Identify improvement opportunities
 - Quantify and manage risks
 - Create increased awareness of the potential for and the value of increased plant performance



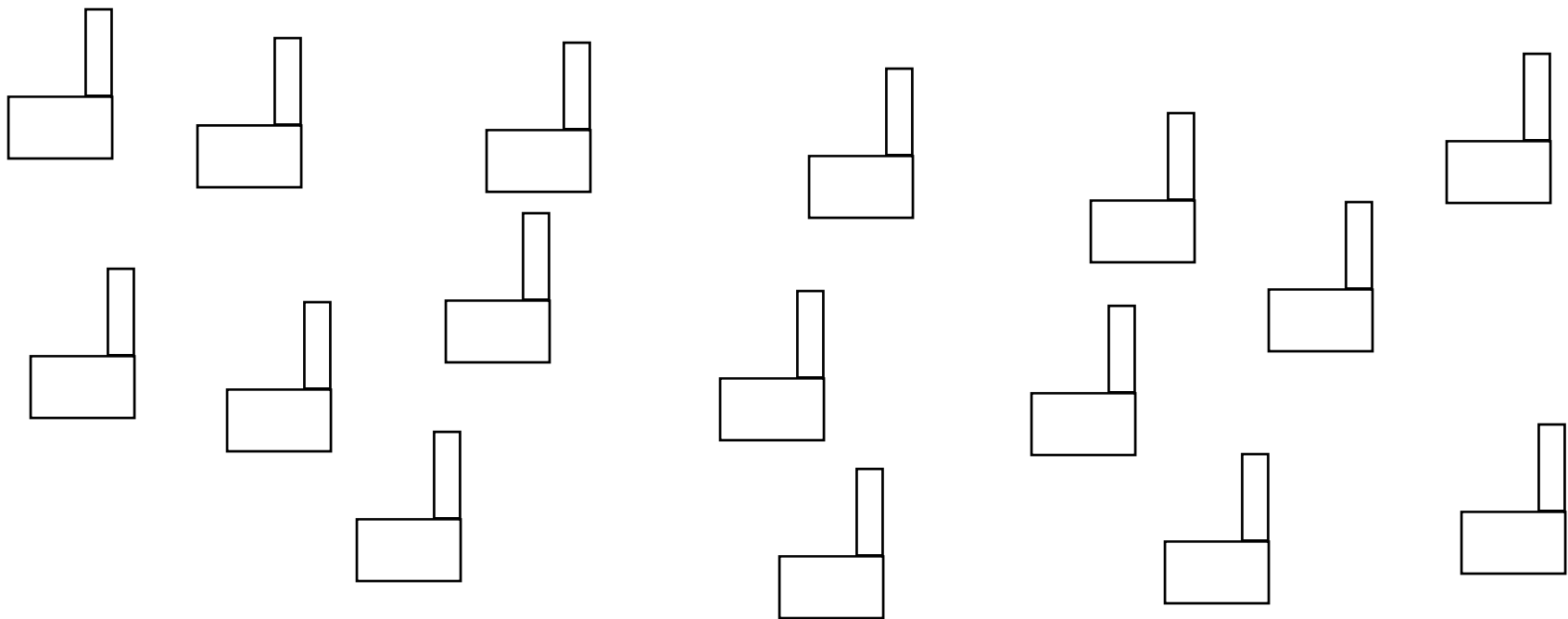
Benchmarking Should be SMART!

- Specific – to the type and operation of the unit.
- Measurable – to show actual changes (+/-)
- Achievable and
- Reasonable – Improvements are possible. Don't expect results that are outside reasonable expectations.
- Tested – that the method of benchmarking has been tested to be a sound, proven technology.



Peer Selection Criteria

Large Population



NERC-GADS Database 7000 + units

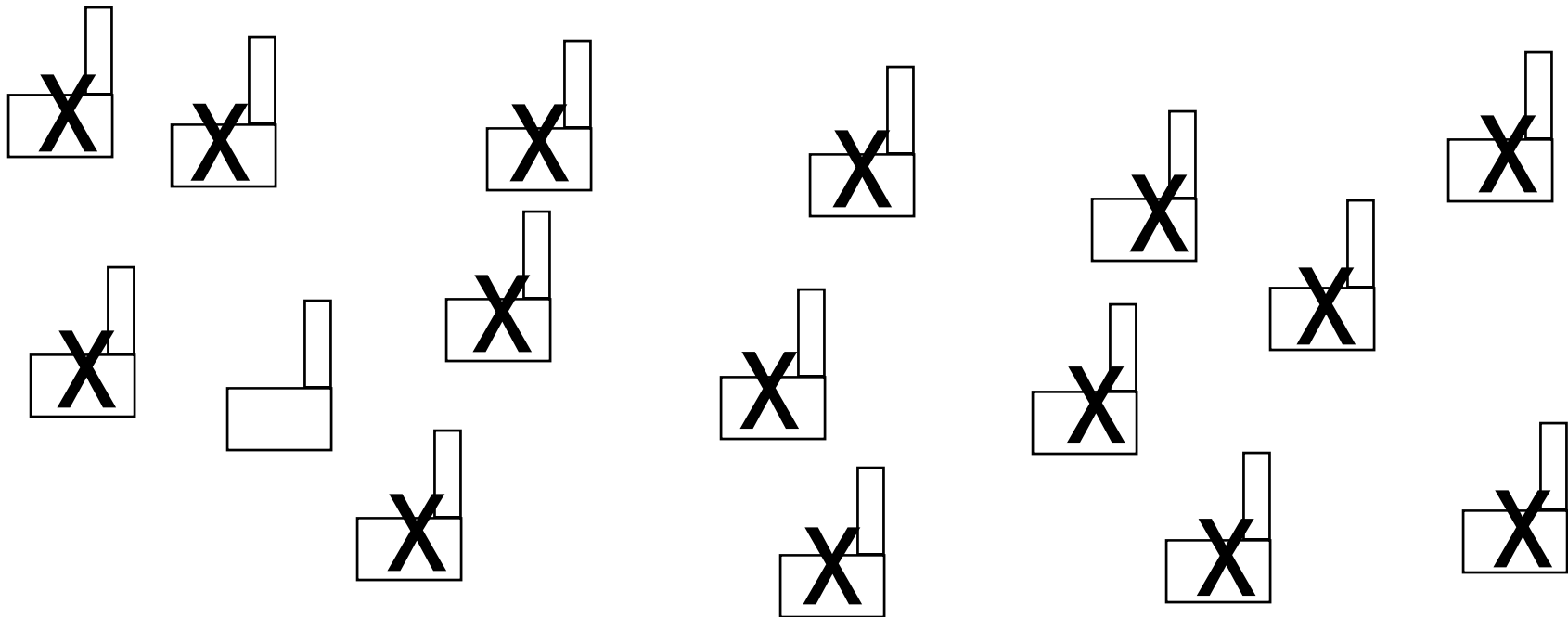


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Peer Selection Criteria

Exact Match



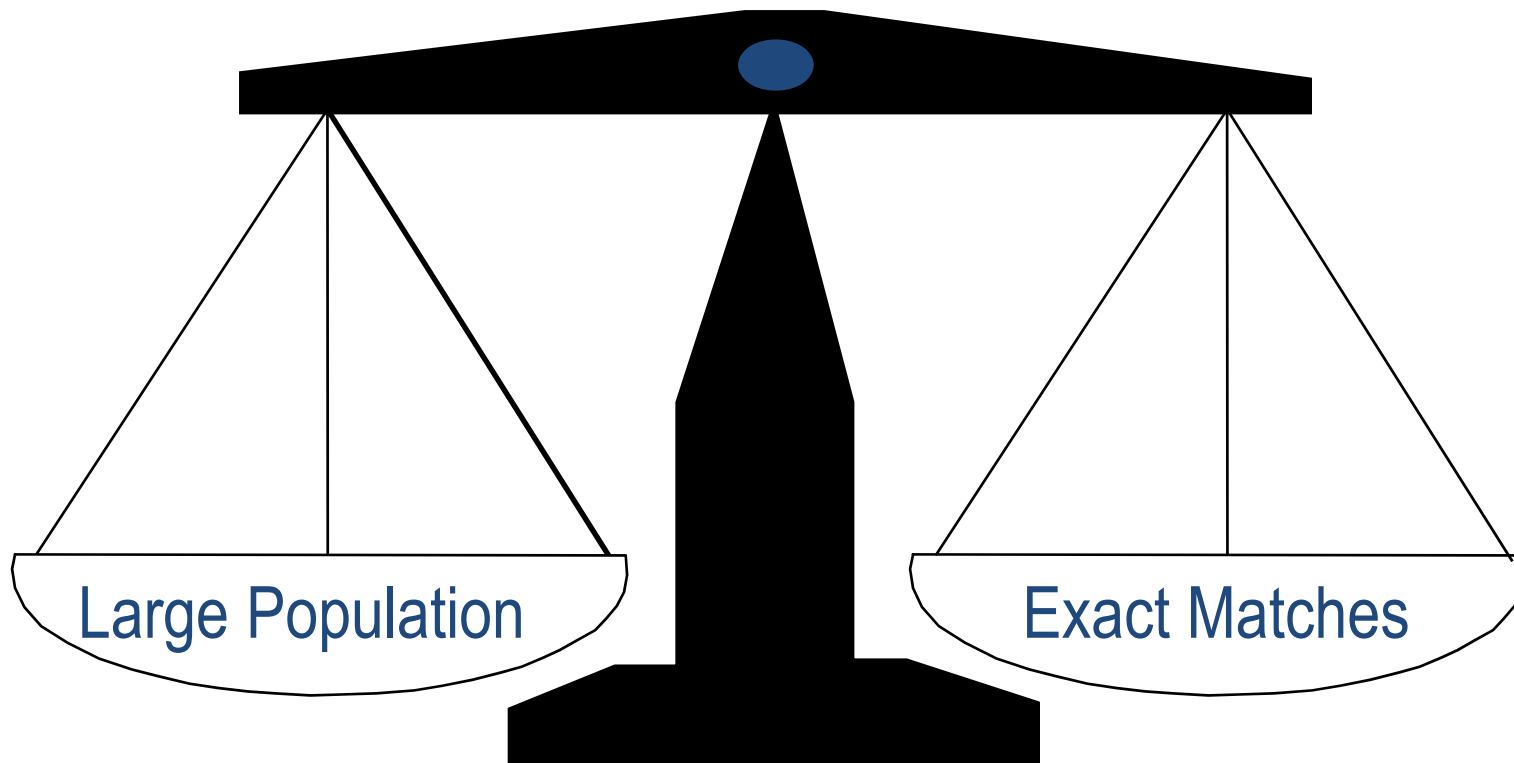
Number of Exact Matches $\longrightarrow 0$



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Peer Selection Criteria



Must Balance Criteria

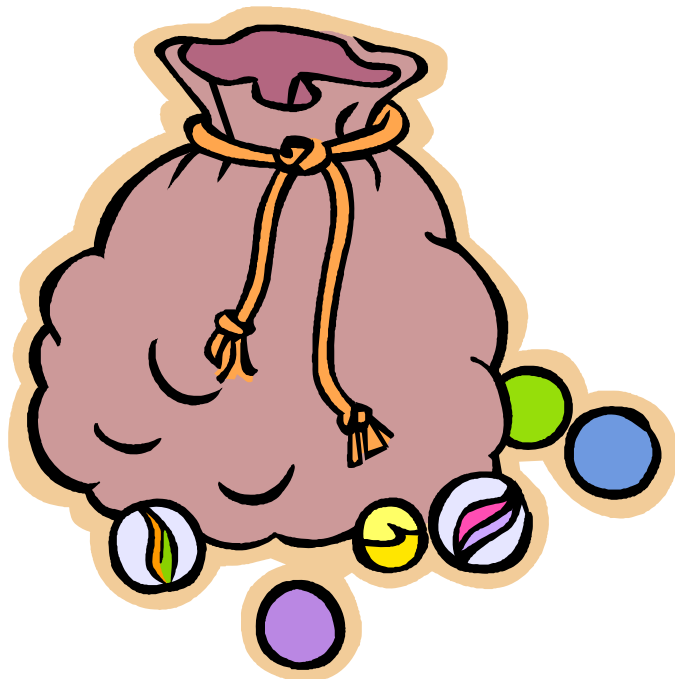


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Easy Peer Group Selection

Bag of Marbles



Golf Balls and BB Pellets



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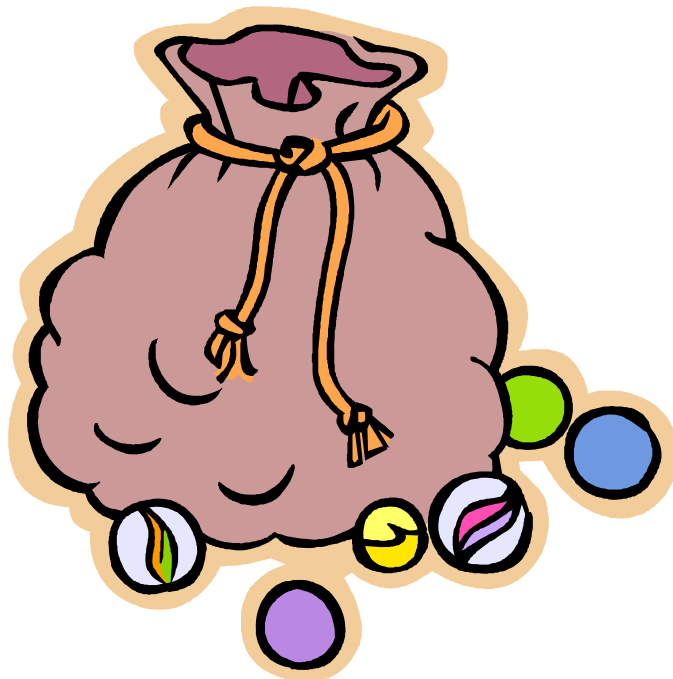
Easy Peer Group Selection

- Should not compare nuclear units to gas turbines.
- Should not compare units constructed 40 years ago to new units with one-year operation.
- Should not compare base-loaded units to those only used occasionally (peakers).



Challenging Peer Group Selection

Bag of Marbles



Same Size, Different Color



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Challenging Peer Group Selection

- Are coal-fired units really different than oil- or gas-fired units?
- Is there a statistical method to show that 199 MW units are different than 200 MW units?
How do you determine when one MW size of units ends and a second group begins?
- Does the performance of manufacturer A differ significantly from that of manufacturer B?



Benchmarking Goal

- Identify generating units (individually) that can be grouped based on both
 - Unit design
 - Operating experience
- Question:
 - Are the selected benchmarking criteria different enough to be different (golf balls and BBs) or
 - Are the selected benchmarking criteria different yet the same (same size marbles)?



What is the Best Benchmarking Metric?

- In the benchmarking definition, it states
 - A measurement of the quality of an organization's policies, products, programs, strategies, etc., and their comparison with standard measurements, or similar measurements of its peers.
- What is the best “measure” for comparing with peers?



Possible Metrics for Benchmarking

- Equivalent Availability Factor (EAF)
 - Measures the percent of time the unit is capable of full load operation.
 - Measure of overall unit performance and has been the comparative measuring metric for power plants for years.
 - Not influenced by dispatch
 - Influenced by outage repairs – PO, MO and FO
 - Not totally independent of external influences



Possible Metrics for Benchmarking

- Net Capacity Factor (NCF)
 - Measures the percent of time the unit was at full load operation.
 - Used as a measure of overall unit loading capability for categories such as base loaded, cycling, etc.
 - Not totally independent of external influences
 - Influenced by dispatch
 - Influenced by outage repairs



Possible Metrics for Benchmarking

- Equivalent Forced Outage Rate (EFOR)
 - Measures the probability of experiencing a forced outage or forced derating.
 - Designed for units operated continually with little or no reserve shutdowns (base-load).
 - Independent of external influences
 - Not influenced by dispatch
 - Not influenced by maintenance or planned outage repairs, not for cycling or peaking units.



Possible Metrics for Benchmarking

- Equivalent Forced Outage Rate Demand (EFORd)
 - Measures the probability of experiencing a forced outage or forced derating during demand periods.
 - Designed for units in all operating states (base-load, cycling, peaking, etc.).
 - Not influenced by dispatch
 - Not influenced by maintenance or planned outage repairs
 - **Best reliability metric – RECOMMENDED!**



How Many Peer Units?

- It is highly recommended that a minimum of 30 generating units should be used to compare against your unit (or group of units.)
 - Less than 30 units can result in a bias (high or low).
 - A distribution of the benchmarking metric can identify any bias.



Benchmarking Options

- Unit benchmarking
 - Review the entire generating unit as a whole and look for what makes the unit “unique.”
- Component benchmarking
 - Review the major component/group of components as a whole and look for what makes the component (s) “unique.”



Unit Benchmarking Option #1

- Traditional method where user selects what options are important and what options are the same.
 - Same steam turbine manufacturer
 - Same fuels burned
 - Using GADS report for determining MW size of the group
 - 100-199 MW
 - 400-599 MW



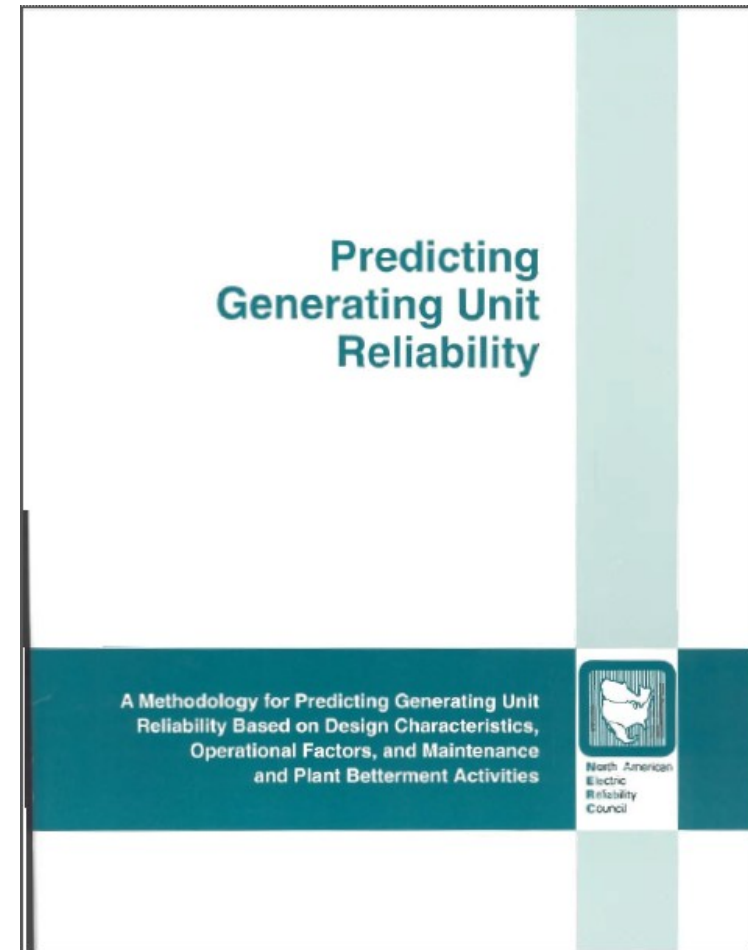
Unit Benchmarking Option #1

- Advantages
 - Many people use it
 - Quick determination of what to use as criteria based on “gut feeling”
- Disadvantages
 - No statistical backup as to prove that one criteria is better than another.



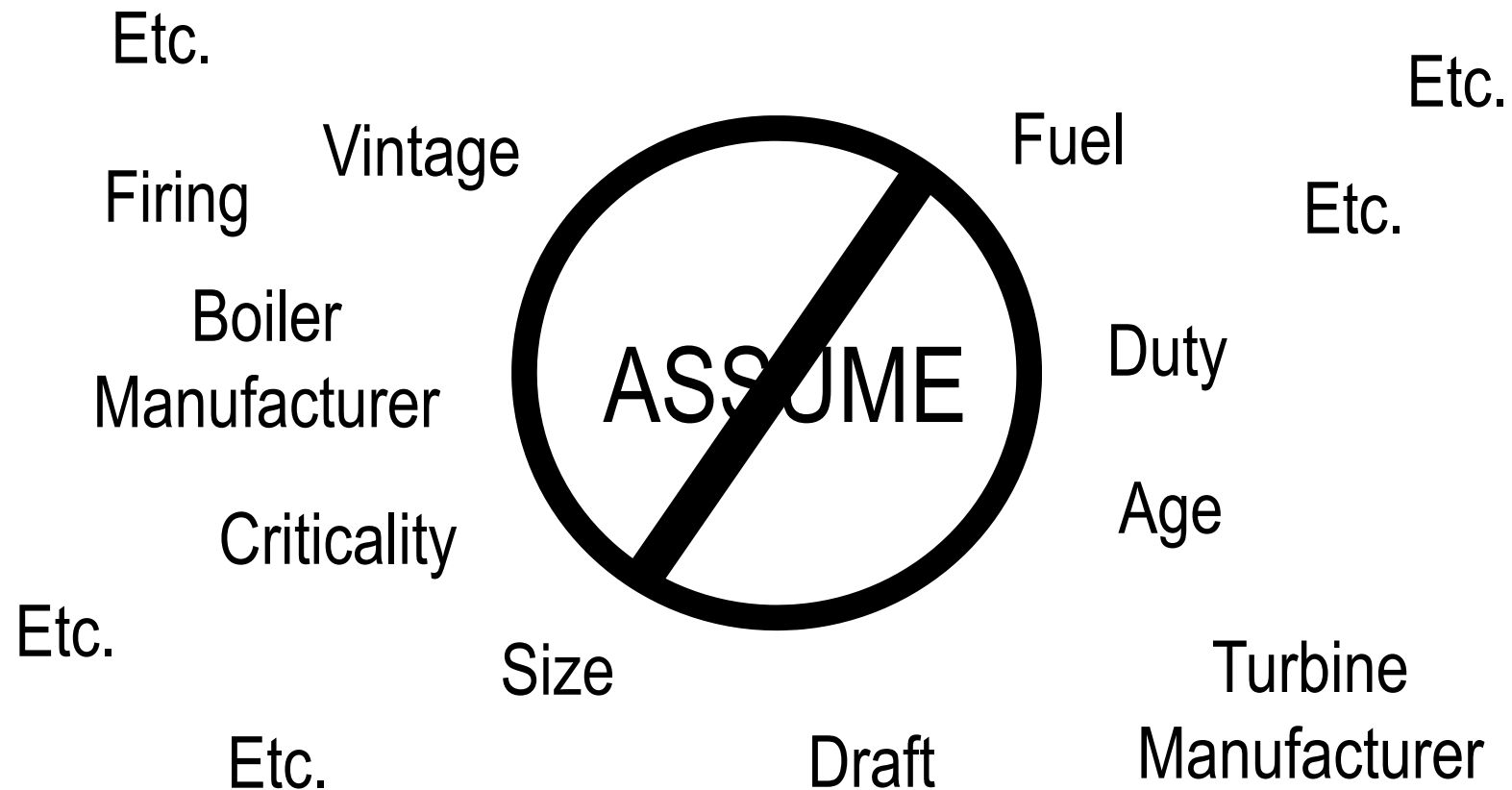
Unit Benchmarking Option #2

- Statistical Analysis Method

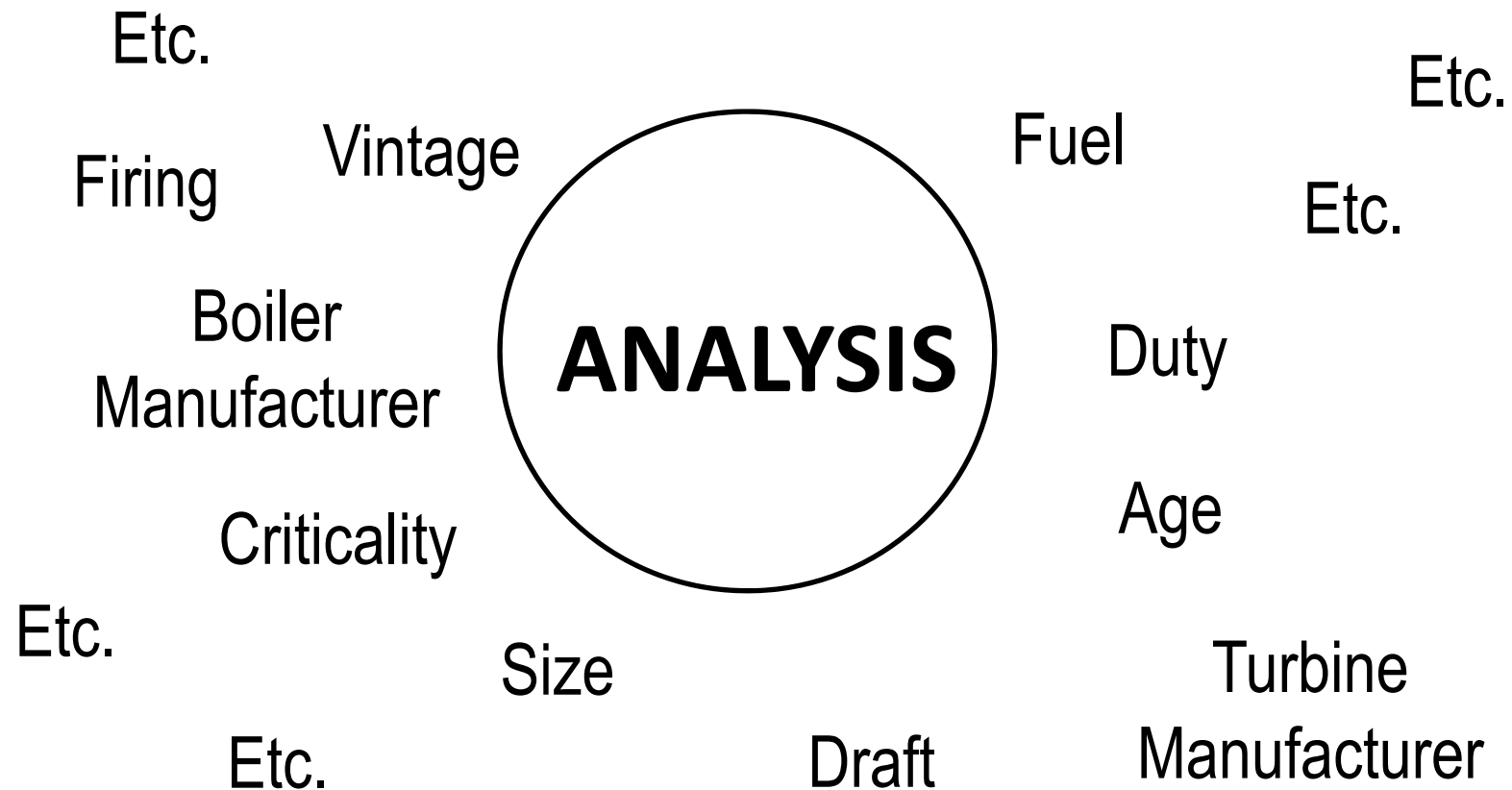


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Peer Selection Criteria

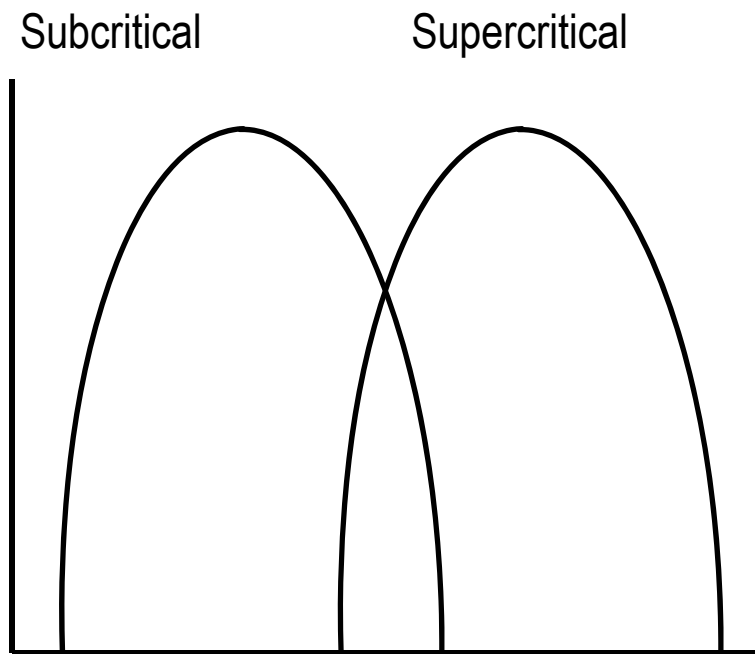


Peer Selection Criteria

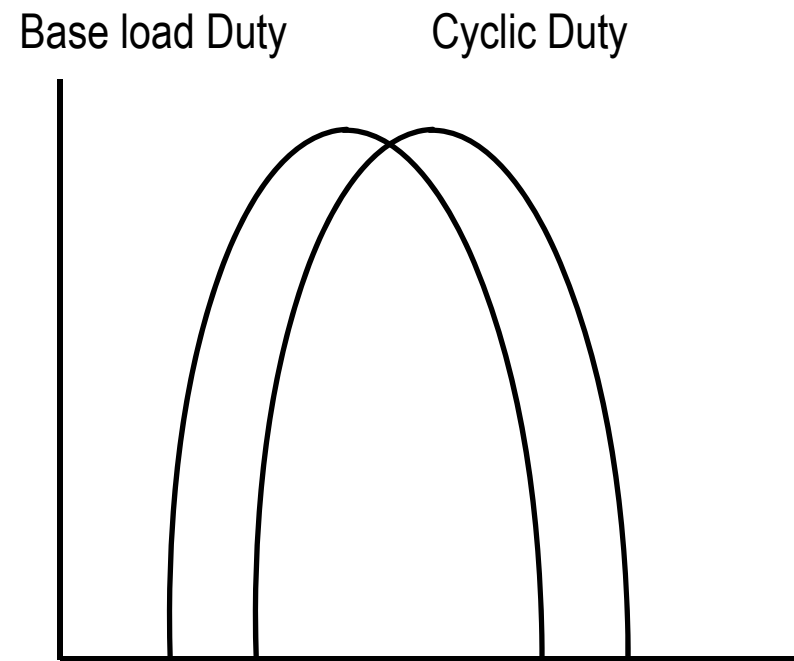


Peer Selection Criteria

Significance Testing



EFORd



EFORd

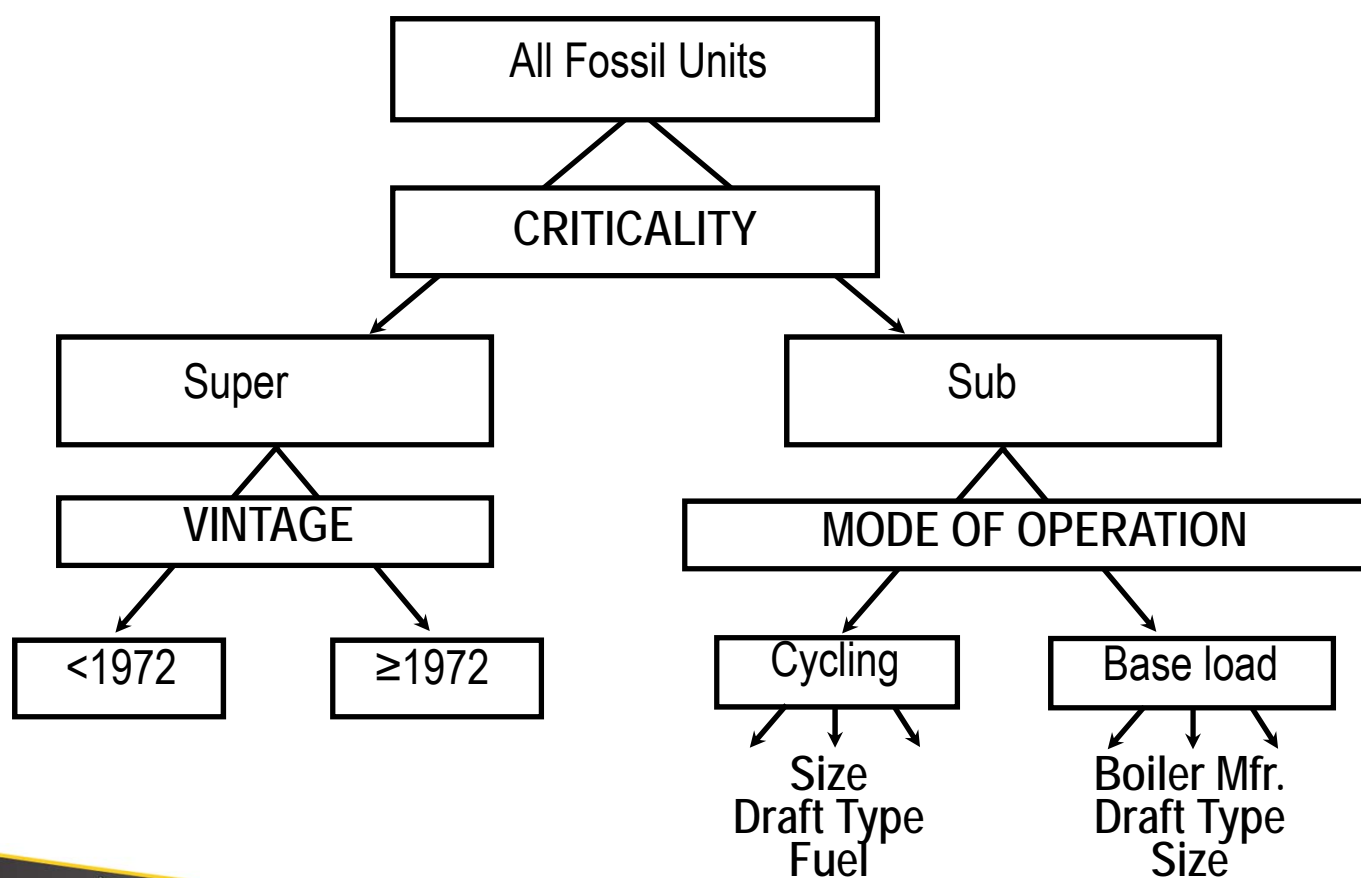


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Peer Groups Select Criteria

Fossil Units



Some Findings

- Golf balls and BBs
 - Nuclear vs. simple cycle gas turbines
 - Subcritical vs. supercritical pressures
 - Balanced vs. pressurized boilers
- Same size marbles
 - Gas vs. oil-fired boilers
 - Steam turbine manufacturer A vs. B



Does Peer Selection Make a Difference?

SUPERCritical FOSSIL UNIT TECHNOLOGY

	<u>EARLY VINTAGE</u>	<u>RECENT VINTAGE</u>
EFORd (mean)	15.60%	9.68%
EFORd (median)	12.17%	8.08%
EFORd (best quartile)	8.14%	5.47%



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Does Peer Selection Make a Difference?

EFORD - PLANT A

OLD CRITERIA (Coal; 100-199MW)		NEW CRITERIA	% DIFFERENCE
mean	6.47%	5.53%	-14%
median	4.78%	5.07%	+6%
best quartile	2.65%	3.26%	+23%



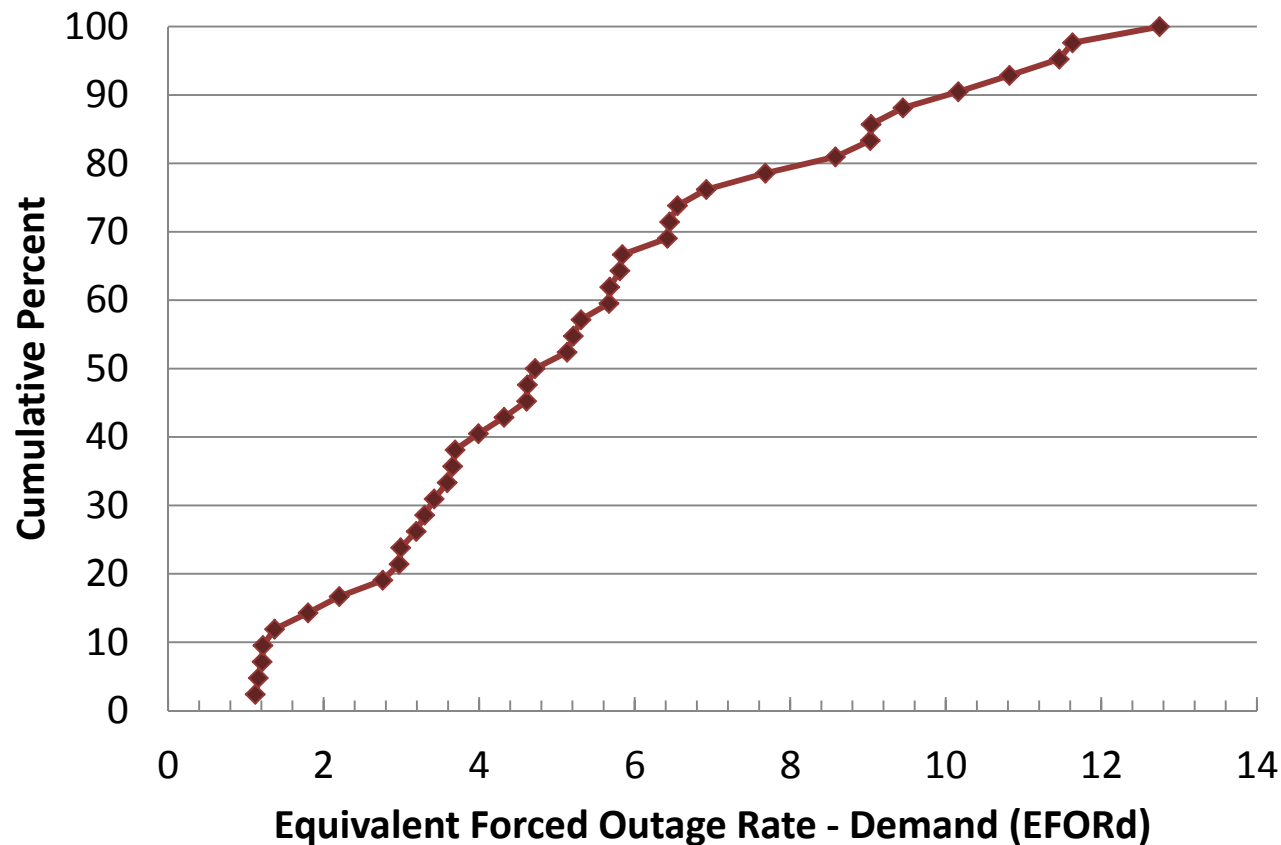
Reliability Benchmarking Results

42 Peer Units

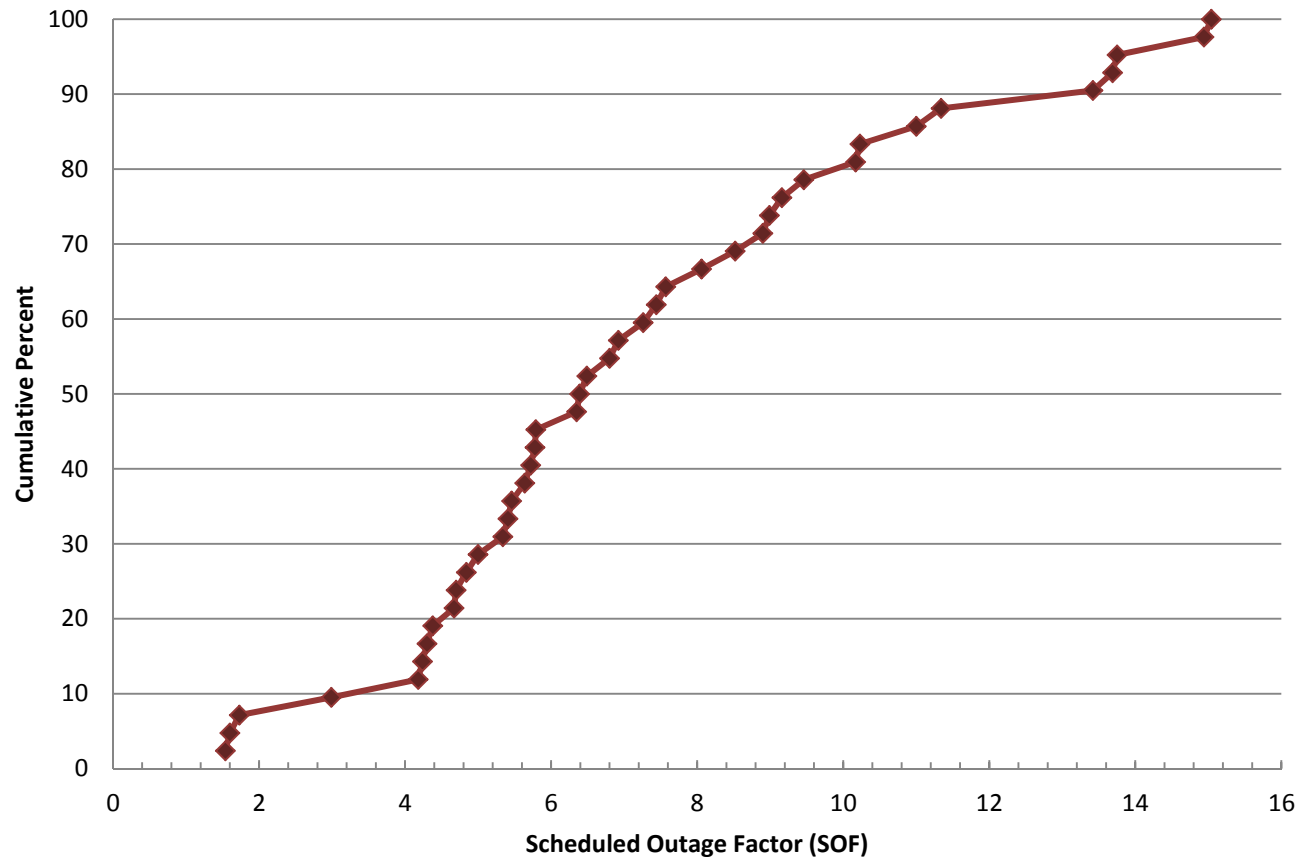
- Peer unit selection criteria
 - Subcritical
 - Reserve shutdown hours less than 963 hours per year
 - Natural boiler circulation
 - Primary fuel = coal
 - Single reheat
 - Net output factor greater than 85.6%



Peer Unit EFORd Distribution



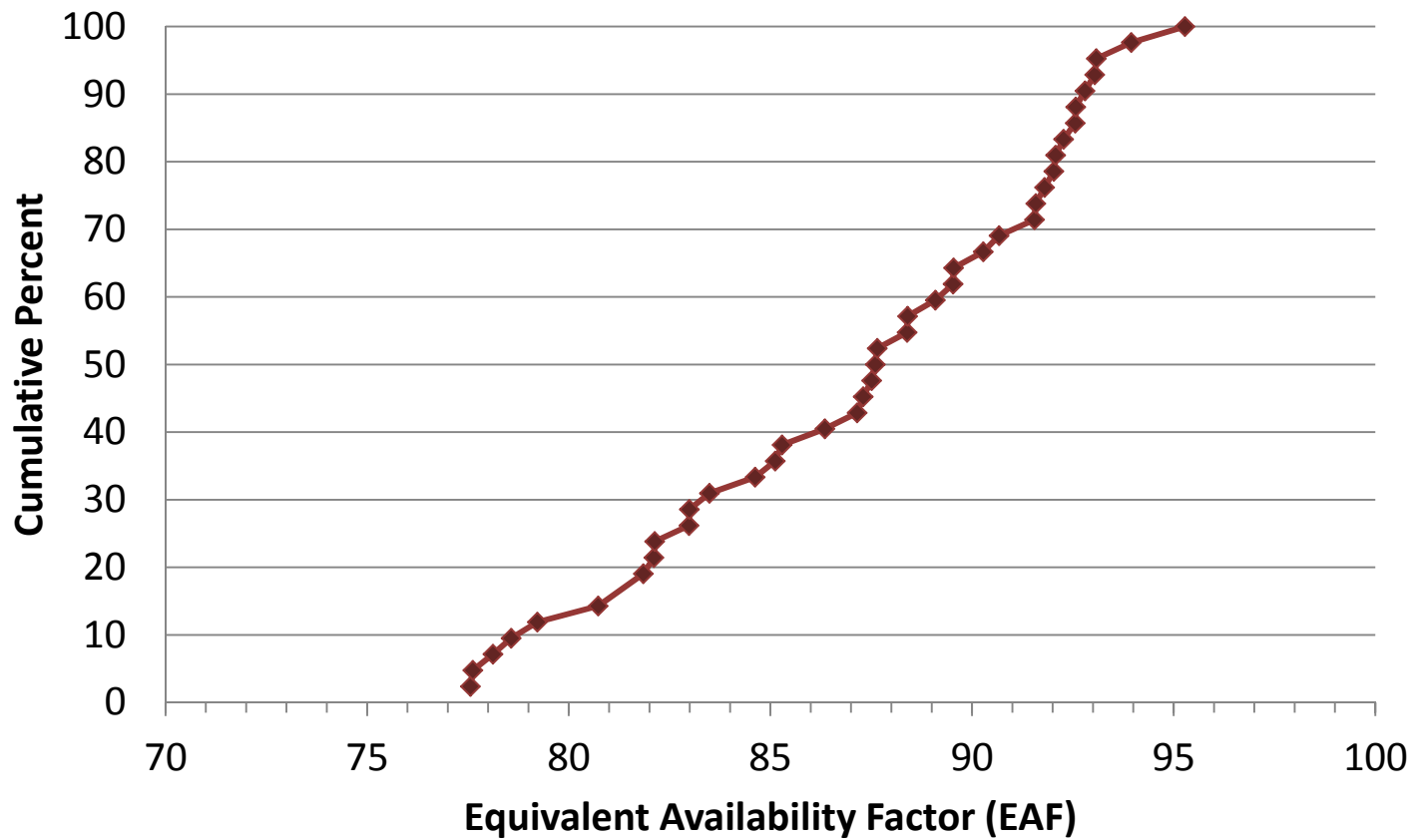
Peer Unit SOF Distribution



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Peer Unit EAF Distribution



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Game Plan

- To simply find ways that either outage frequency, outage duration, or both, can be reduced and kept at a level consistent with minimum generation costs and load management objectives.



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Mother Lode “Shopping List”

List of Top 10 Causes of Forced Outages

Rank	Cause Code	Description	Occurrence per Unit Year	MWH per Occurrence	MWH per Unit Year
1	1050	Second Superheater Leaks	1.01	19,697.83	19,987.16
2	1000	Waterwall (furnace Wall)	0.43	25,896.34	11,226.20
3	1040	First Superheater Leaks	0.28	26,940.82	7,443.75
4	1060	First Reheater Leaks	0.19	27,473.08	5,235.04
5	4520	Gen. Stator Windings; Bushings; And Terminals	0.02	221,062.64	4,212.39
6	1080	Economizer Leaks	0.17	24,105.14	4,133.95
7	3620	Main Transformer	0.07	54,428.70	3,889.31
8	3659	Other Dc Power Problems	0.03	124,869.58	3,569.12
9	4470	Differential Expansion	0.04	92,785.69	3,536.10
10	1090	Other Boiler Tube Leaks	0.10	34,137.96	3,252.52

Data from NERC pc-GAR software.



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Conclusions

- Benchmarking is helping utilities by
 - Helping set reasonable goals
 - Identifying improvement opportunities
 - Quantifying and managing risks
 - Creating increased awareness of the potential and value of increased plant performance
- Proper peer group selection is essential!



Questions?



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Thank you!

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