FLEX EQUIPMENT RELIABILITY DATA

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Post Fukushima, Utilities have invested significant resources in procuring Flex Equipment and developing guidance for using the equipment for beyond design basis external hazards. NEI 16-08 "Guidance for Optimizing the Use of Portable Equipment" urges utilities to leverage this investment by using Flex or other portable equipment to provide additional safety benefits. These safety benefits can be quantified by including Flex equipment in the site-specific PRA models. This can provide additional margin for various risk informed applications, such as TSTF-505 "Provide Risk-Informed Extended Completion Times - RITSTF Initiative 4b", Significance Determination Process evaluations and the Mitigating Systems Performance Index. Modeling Flex equipment in utility PRA models requires the development of reliability data, which is currently unavailable. The PWROG, with support from the BWROG, is currently developing failure data for the most credited Flex equipment. This paper will summarize the results of this evaluation including the approach used in developing the data, component boundaries, failure definitions, sources of uncertainty as well as the failure rates. Finally, lessons learned from the development of the data will be reported.

I. BACKGROUND

Post Fukushima, Utilities have invested significant resources in procuring Flex Equipment and developing guidance for using the equipment for beyond design basis external hazards. NEI 16-08 "Guidance for Optimizing the Use of Portable Equipment" urges utilities to leverage this investment by using Flex or other portable equipment to provide additional safety benefits. These safety benefits can be quantified by including Flex equipment in the site-specific PRA models. This can provide additional margin for various risk informed applications, such as TSTF-505 "Provide Risk-Informed Extended Completion Times - RITSTF Initiative 4b", Significance Determination Process evaluations and the Mitigating Systems Performance Index. Modeling Flex equipment in utility PRA models requires the development of reliability data, which is currently unavailable. The PWROG, with support from the BWROG, has developed failure data for the most credited Flex equipment. This paper provides the results of this evaluation including the approach used in developing the data, component boundaries, failure definitions as well as the failure rates. Finally, lessons learned from the development of the data will be reported.

The US nuclear utilities and the National SAFER Response Centers, in coordination with EPRI Nuclear Maintenance Application Center (NMAC) develop a preventative maintenance (PM) Database to capture operating experience to optimize Flex equipment PM tasks. This database provides a valuable resource for meeting this goal, but additional information is needed to develop failure rates for use in PRA models. For example, the current framework does always capture how many pieces of equipment or number of different PM tasks for each equipment type (beyond the original intent of the database)

II. PLAN

The plan for developing Flex Reliability Data included:

- Determining Scope/Boundary conditions

- Data request survey
- Data evaluation
- Failure rate calculation
- Report Generation
- NRC Review/Comment
- Final Report
- Follow-up Actions

III. SCOPE

Not all Flex equipment is modeled in the PRA. The scope of equipment to be evaluated was determined as follows:

III.A. Component types:

A team of utility PRA practitioners was convened to identify and reach consensus on the types of Flex equipment that was most commonly being credited in PRAs or risk informed decisions making (e.g., Significance Process Determinations, NOEDs, Exigent Technical Specification Changes, etc.). This was supported by an industry survey. The team also determined that all credited Flex equipment (portable and permanently installed) should be evaluated. The evaluation will include a determination of whether there is a difference in failure rates. These components were determined to be:

- Diesel Generators
  - High and Moderate Voltage
- Combustion Turbine Generators
  - High and Moderate Voltage
- Diesel-Driven Centrifugal Pumps
  - High, Medium and Low Pressure/Flow Rate
- Diesel-Driven Positive Displacement Pumps
  - High, Medium and Low Pressure/Flow Rate
- Diesel-Driven Positive Displacement Pumps
  - High, Medium and Low Pressure/Flow Rate
- Motor-Driven Positive Displacement Pumps
  - High, Medium and Low Pressure/Flow Rate
- Diesel-Driven Air Compressors
- Motor-Driven Air Compressors

III.B. Boundary Conditions:

To ensure consistency in data evaluation, a standard definition of failure types and component boundaries was needed. Though the industry is generally moving to using the MSPI Failure types in their models e.g., Failure on demand (including the first hour of run time), Failure to run and failure to load/run for diesel generators, use of these definitions creates problems for Flex equipment which is rarely run for greater than an hour during testing under the PM process. The team determined the following criteria were appropriate for Flex equipment:

- Failure on demand (limited restart attempts can be credited)
- Failure to run (from time of successful start)

During the NRC/INL audit of the flex data, it was determined that due to the sparse data, the component types should be combined. As a result, the component types and component boundaries used are shown in Table 1:

Table 1: Component Boundaries

Component Type	Boundary
Portable Diesel Generator	The diesel generator boundary includes the diesel engine with all components in the exhaust path, electrical generator, generator exciter, combustion air, lube oil systems, fuel oil systems and starting compressed air system, and local instrumentation and control circuitry. Additionally, starter batteries are included.
Portable Combustion Turbine	The combustion turbine generator boundary includes the gas turbine, generator, circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. Additionally, starter batteries are included.
Portable Diesel-Driven Pump	The diesel-driven pump boundary includes the pump, diesel engine, local lubrication or cooling systems, and local instrumentation and control circuitry. Additionally, starter batteries are included.
Portable Motor-Driven Positive Displacement Pump	The positive displacement pump boundary includes the pump, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry.
Portable Diesel-Driven or Motor-Driven Air Compressor	The air compressor boundary includes the compressor, driver, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. Additionally, starter batteries are included.

III.C. Data Collection:

To obtain reliability data for Flex Equipment, the following data request was sent to all US utilities:

- If the site has already performed data analysis on the FLEX equipment of interest, the site can provide the input information from their individual analysis; however, the information provided should have the same level of detail as described below.
- For other sites, it was recommended that the starting point for demand/run hour data be the EPRI PM Database. It was noted that the PM Database was not developed for obtaining PRA failure rates and the data needs to be verified by the utility prior to sending it to the PWROG. The database should be used to provide the following information:

- The utility name and site name.
- Component type (See Table 1), along with make and model of the component. Additionally, provide
- the number of each type of component at the site.
- The operating hours to date for the component(s). (This can be estimated by using the number of tests/maintenance runs and estimated hours per test/run)
- The date in which PM activities for the component began.
- The frequency and duration of each PM (note that for some plants, individual line items may include multiple PMs or there may be multiple tasks within a PM. Please provide a summary of each PM task). Also note that PM information is only requested for PMs that operate equipment. PM tasks that do not operate equipment can be excluded.
- Identify any changes to the PMs (since the PM was first started), tasks, or frequencies and the date those changes were effective.
- For any identified adverse condition provide the documentation of the condition and corrective action (e.g., work orders, CRs, etc.)
- The site reference document.
- Any additional comments.

IV. DATA EVALUATION

There were 99 plants that reported data for inclusion in this analysis. Each component was assigned a unique component designator representing the utility, site, component type (e.g., Portable Diesel-Driven Centrifugal Pump) operating range (e.g., High Pressure Low Flow) and a single digit identification number. Note that although the final component grouping does not consider operating range, this level of detail is maintained in the database for potential use in future updates as more data becomes available.

Run time was generally provided by utilities in one of two basic ways: (1) on a per component basis or (2) as a summation for a component group. When run-hour figures were provided on a component basis, they were applied directly to the respective component. When run-hour data was provided for a component grouping, the run-hours were divided equally amongst the components in the group. In some instances, run hours were not provided by the utility. In these cases, if the utility provided valuable information for the other categories, the data analysts made an estimate of the number of run-hours to make the best use of the data provided. Where run-hour estimates were made, these estimates were established based on the reported PM frequency, the date of the initial PM, and an assumed duration based on the type of PM. Based upon observation from the utilities that provided run-hour data, it appears that the PM related runs for FLEX equipment are relatively short in duration. This observation led to assigning a value of 0.5 run-hours for PMs with a frequency of less than 1 year and a value of 1.0 run-hours for each PM with a frequency of greater than or equal to 1 year.

The demand data was compiled based on the reported PM frequency, the start date of the PM, and the date in which the data from the respective utilities was received. Like the run time data, there was a varied range of completeness and usability across the responses that were provided. For instance, if a utility did not provide information related to the time in which the PM was established (date of initial PM) but had an identified event that occurred in 2016 then January 1, 2016, was assumed to be the start date of the PMs at the utility.

DATA COLLECTION

The 99 plants included in this analysis experienced a total of 794 events from the adoption of FLEX strategies at each site through (roughly) 2019[1]. The events in this analysis were binned into Failure Criteria based upon the brief description of the event from the respective utilities' Corrective Action Program (CAP). It is recognized that in its current form, the data may contain infant mortality type failures that do not represent long term component reliability. As future data collection efforts are performed, these failures may be pruned from the data used to calculate component failure rates.

The analysts made judgements regarding the reported events in two areas: (a) whether the event was a failure and (b) for events determined to be failures, whether the failure mode was fail-to-start (FTS) or fail-to-run (FTR). The available events were reviewed to determine if any failures (specifically for the diesel generators) were representative of a fail-to-load failure mode. At most, one event was identified as a potential fail-to-load event.

Regarding the failure mode, analysts used the following logic to determine whether the failure was FTS

or FTR:

> Considering the short operating periods the FLEX equipment is typically run, distinguishing between a run or start failure is made by determining if the component reached a functional level of steady-state operation rather than a set amount of time. For instance, if a component started but never reached a stable running state, it was classified as a failure to start rather than a failure to run, despite technically running for a short period of time. On the other hand, if a component had been started and reached a stable running state for any amount of time and then subsequently failed, it was classified as a failure to run event.
>
> Additionally, when evaluating whether an event was a failure to start, consideration was given to repetitive attempts to start equipment. If there were multiple attempts to start equipment, and the equipment was successfully started within a short time, without significant troubleshooting, the event was screened as not being a failure.
>
> Finally, consideration was given as to whether an event was considered recoverable. Conversations were held with FLEX PM Coordinators on specific battery failures that could be corrected quickly (<15 minutes) and included actions that were proceduralized. Recovery could be explicitly credited in development of the failure rates, but for consistency with how permanent plant equipment failure rates are developed, was not credited in this analysis.

Derivation of FLEX Equipment Unreliability Parameters

Three (3) approaches were defined to generate generic failure rate estimates, based on the amount of plant information available. These three methods are described below. The Bayesian update using Jeffreys noninformative prior, was used as the default approach if the other methods could not be justified.

Empirical Bayes Approach

If a statistically significant difference in mean values was determine for a given set of data, generic failure rate estimates were derived using the empirical Bayes (EB) approach. This approach effectively pools component reliability data at the plant-level, rather than pooling data at the industry level.

The U.S. NRC maintains an EB calculator on the NROD (Nuclear Reliability and Operating Experience Database) website. This calculator provides a convenient user interface to provide consistent results.

Bayesian Update Using Jeffreys Noninformative Prior

In cases where a statistically significant difference in mean values was not found, a different approach is required for parameter estimation. A Jeffreys noninformative prior (JNI) is used where sufficient operating experience exists.

For demand failures (λ_d), the JNI is a beta distribution with parameters $\alpha = 0.5$ and $\beta = 0.5$; similarly, for run-time failure rates (λ_h), the JNI is a gamma distribution with $\alpha = 0.5$ and $\beta = 0$. By using the Bayesian update formulas, the posterior means for a beta and gamma distribution can be determined.

$$\lambda_d = \frac{\alpha_{prior} + n_f}{\alpha_{prior} + n_f + \beta_{prior} + n_d - n_f} = \frac{n_f + 0.5}{n_d + 1}$$

Where n_f = number of failure events, n_d = number of demands, and t = number of run-hours.

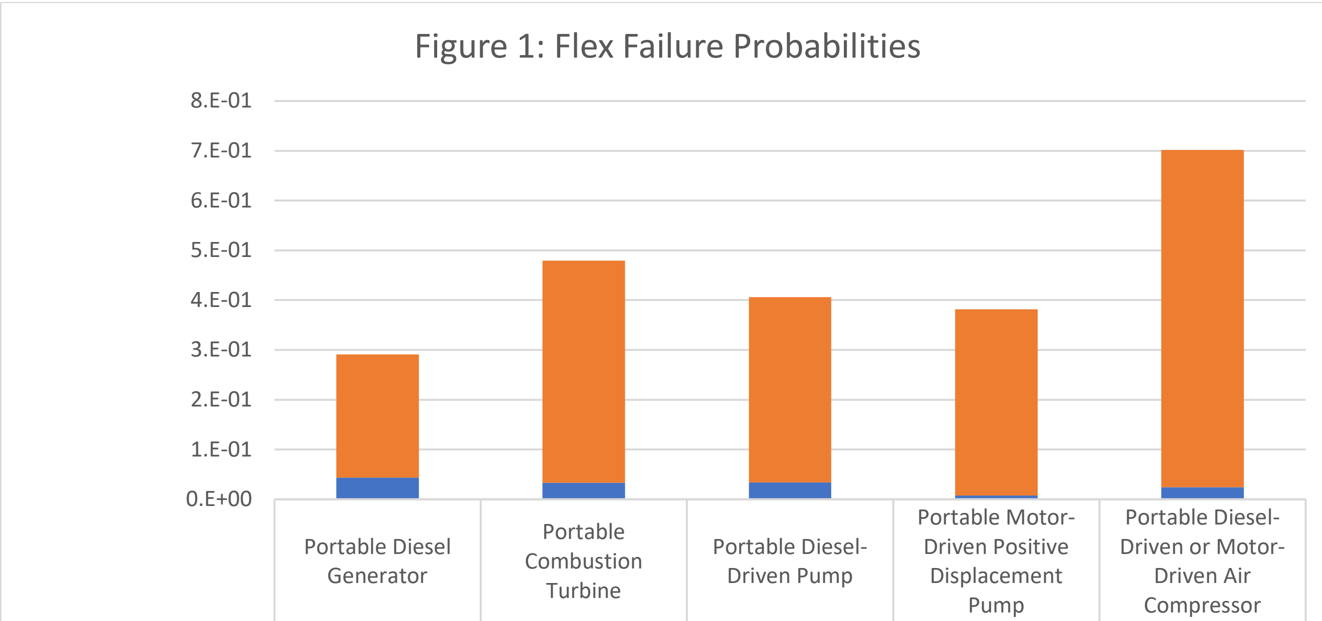
Bayesian Update Using Constrained Noninformative Prior

The third method considered for this analysis is implemented by specifying a mean value, based on some prior belief, but ensuring that the dispersion corresponds to ignorance (in some objective sense). The distribution matching these characteristics is known as the Constrained Noninformative Prior Distribution (CNID).

For situations where the exposure is less than 50 (demands or operating hours), a CNID would be calculated and updated with the industry specific failure information to obtain posterior distribution parameters, and in effect, posterior mean values. The final grouping of components resulted in no equipment meeting the criteria to implement the CNID.

RESULTS

Figure 1 provide point estimates for the failure rates of flex components.



	Portable Diesel Generator	Portable Combustion Turbine	Portable Diesel-Driven Pump	Portable Motor-Driven Positive Displacement Pump	Portable Diesel-Driven or Motor-Driven Air Compressor
Fail to Run 24 hours	0.2472	0.4464	0.372	0.3744	0.6768
Fail to Start	4.35E-02	3.30E-02	3.38E-02	7.35E-03	2.46E-02

V. PRELIMINARY LESSONS LEARNED

- Improvements to the process used for sites to provide data is needed. This includes a set of failure definitions to be used by the sites to screen events as potential failures so that they can be readily identified in the site documentation for future data evaluation. Recommendations will be provided to the Risk Informed Steering Committee for consideration at the end of the project.
- Sites use different maintenance strategies for their Flex equipment. This can impact whether an event is considered a failure for that site. As an example, some sites use battery chargers to continuously provide a trickle charge to the battery. For these sites, failures that result from a dead battery may not represent a failure for that site. This should be accounted for by a plant specific Bayesian update.
- Personnel providing the demand and run data need a good understanding of how the data was entered into the EPRI PM database. high turnover rate of Flex maintenance/program owners has complicated obtaining the correct data.
- Due to the sparse data, component groups were combined (e.g., all diesel generators were combined into 1 group rather than being separated by capacity). As more data becomes available, the component groups may change. This was identified during the NRC audit of the report.
- It was originally planned to include data from the 2 SAFER centers. During the initial review of the data, it was identified that the equipment at the SAFER was modified to allow for air transport to the sites. Due to resource and time constraints, it wasn't possible to evaluate these modifications to determine if these changes would impact the failure

rates. The next update includes plans to evaluate these changes to determine if it is appropriate to include data from the SAFER centers in the pool of data. This would significantly expand the available data set.

VI. FUTURE ACTIVITIES

- As Flex data was only available for a few years, an update of the failure rates is planned to cover data through the end of 2021.
- As plants add credit to their PRA models, the need for data for additional equipment will be evaluated.

VII. CONCLUSIONS

Failure to run rates for flex equipment were calculated to be higher than expected. This is driven by a small number of failures with very low run hours (flex equipment is rarely run for greater than an hour). It is hoped that with addition data and as the sites take corrective actions from the early failures, these failure rates will decrease.

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