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Mitigating Systems Performance Index Baselines

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Abstract

This paper discusses the technical assessment of recommended train unavailability and component unreliability baselines for the US Nuclear Regulatory Commission Mitigating Systems Performance Index. To perform this evaluation, recent data were compared with the recommended baselines. Comparisons indicate that the recommended baselines appear to accurately represent recent (1999 – 2001) industry experience.

1 Background

The Mitigating Systems Performance Index (MSPI) is a proposed Performance Indicator (PI) for US commercial nuclear reactors that would replace the existing US Nuclear Regulatory Commission (NRC) Reactor Oversight Process (ROP) mitigating system PIs. For each mitigating system addressed, the MSPI (change in core damage frequency, or ΔCDF) is defined as the following [1]:

$$MSPI = UAI + URI \qquad \text{(Eq. 1)}$$

$$UAI = CDF_p \sum \left[\frac{FV_{UAp}}{UA_p} \right] (UA_t - UA_{BLt}) \qquad \text{(Eq. 2)}$$

$$URI = CDF_p \sum \left[\frac{FV_{URp}}{UR_p} \right] (UR_c - UR_{BLc}) \qquad \text{(Eq. 3)}$$

UAI is evaluated on a train unavailability (UA) basis and summed over all trains within the system. URI is evaluated on a component unreliability (UR) basis and summed over all monitored components within the system. Terms with the subscript "p", including the Fussell-Vesely (FV) importance, are determined from the plant probabilistic risk assessment (PRA). The terms UA_t and UR_c represent plant-specific estimates (obtained from performance data over the most recent three years), while the terms UA_{BLt} and UR_{BLc} represent baseline estimates against which the current values are compared. The MSPI for a mitigating system is then an approximate measure of the plant ΔCDF resulting from changes in system UA and UR performance relative to prescribed baseline performance.

This paper discusses the technical assessment of recommended UA and UR baselines for the MSPI. To perform this evaluation, recent data were compared with the recommended baselines. Comparisons indicate that the recommended baselines appear to accurately represent recent (1999 – 2001) industry experience. The originality of this work involves the comparison of recommended UR baselines with recent unpublished data from industry and US NRC programs and the evaluation of whether plant-specific or industry-average train UA baselines should be used.

2 Evaluation of Recommended UR Baselines

The MSPI monitors unreliability performance of pumps, emergency diesel generators, and selected valves in five types of mitigating systems: emergency ac power (EAC), high-pressure injection (HPI or HPCI), heat removal (AFW or RCIC), decay heat removal (RHR), and cooling water support (SWS and CCW). Therefore, component unreliability baselines are required for emergency diesel generators (EDGs); motor-driven, turbine-driven, and diesel-driven pumps (MDPs, TDPs, and DDPs, respectively); and motor-operated and air-operated valves (MOVs and AOVs). Also, these unreliability baselines should reflect recent performance of such components at US commercial nuclear reactors. To meet these requirements, the MSPI proposes to use industry-average component-type failure rates published in the journal article "Historical Perspective on Failure Rates for US Commercial Reactor Components" [2]. The failure rates in the journal article were generated using information from the Equipment Performance Information Exchange (EPIX) database over the period 1999 – 2001 [3]. Failure data submitted to EPIX include events detected during periodic testing and during unplanned demands. To evaluate whether these failure rates are appropriate for use in the MSPI, comparisons were made with plant-specific data submitted by 20 plants during the MSPI pilot program. Results are summarized in Table 1. The quality of the pilot plant data submitted might be higher than similar information submitted to EPIX, but the pilot plants represent only 20 of the 103 US commercial reactors that report data to EPIX. In general, the MSPI pilot plant data agree reasonably well with the recommended MSPI UR baselines. However, a single DDP at one of the pilot plants appears to be degraded [provided several fail to start (FTS) and fail to run (FTR) events within the three-year period of data collection]. This is reflected in the resulting DDP FTS and FTR values obtained from the pilot plant data, which are higher than the MSPI recommended baselines.

Also, comparisons were made using data from recent updates to older, published US NRC system studies [e.g., 4]. These studies typically include failures detected during unplanned demands. However, depending upon the system, some types of periodic tests (mostly 18-month shutdown tests) are also included. To perform these comparisons, approximate adjustments were made to the updated system study data to eliminate failures outside the MSPI component boundary and to place FTR events occurring within the first hour of operation into the FTS category. Again, results from these comparisons indicate that the failure rates presented in the journal article accurately represent industry performance over the period 1999 – 2001 and are appropriate for use in the MSPI.

Component	Failure Mode	Mean Failure Probability or Rate		
		MSPI Baseline	MSPI Pilot Program Plant Data (3Q1999 – 2Q2002)	Updated NRC System Study Data (? – 2001)
MOV	FTO/C	7.0E-4/d	1.4E-3/d	<9.8E-4/d
AOV	FTO/C	1.0E-3/d	6.3E-4/d	No data
MDP Standby	FTS	1.9E-3/d	4.4E-4/d	2.5E-3/d
	FTR (>1h)	5.0E-5/h	3.0E-5/h	<2.4E-4/h
MDP Running	FTS	1.0E-3/d	5.0E-4/d	No data
	FTR (>1h)	5.0E-6/h	1.2E-5/h	No data
TDP Standby, AFW	FTS	9.0E-3/d	2.8E-3/d	9.7E-3/d
	FTR (>1h)	2.0E-4/h	<2.4E-4/h	No data
TDP Standby, HPCI/RCIC	FTS	1.3E-2/d	<4.7E-3/d	1.2E-2/d
	FTR (>1h)	2.0E-4/h	<2.4E-4/h	No data
DDP Standby	FTS	1.2E-2/d	2.1E-2/d	<1.0E-2/d
	FTR (>1h)	2.0E-4/h	4.8E-3/h	No data
EDG Standby	FTS	5.0E-3/d	3.1E-3/d	Not updated
	FTLR	3.0E-3/d	3.4E-3/d	Not updated
	FTR (>1h)	8.0E-4/h	5.8E-4/h	Not updated
Circuit Breaker	FTO/C	8.0E-4/d	No data	No data

Acronyms: AFW (auxiliary feedwater system), AOV (air-operated valve), DDP (diesel-driven pump), EDG (emergency diesel generator), FTLR (fail to load and run for 1h), FTO/C (fail to open or close), FTR (fail to run), FTS (fail to start), HPCI (high-pressure coolant injection), MDP (motor-driven pump), RCIC (reactor core isolation cooling), TDP (turbine-driven pump)
Notes: FTS includes FTR events that occur within the first hour of operation. All failure probabilities and rates were obtained using a Bayesian update with a Jeffreys noninformative prior. “<” indicates no failures. The start date for system study data varies by component.

Table 1. Comparison of MSPI component failure rate baselines with other sources of data.

One unusual guideline associated with the MSPI UR baselines is the inclusion of FTR events occurring within the first hour within the FTS category. This guideline provides a simplistic way to account for standby pumps and EDGs having different FTR rates for operation during the first hour and for continued operation after the first hour. (In the journal article discussed previously, FTR rates are presented for both periods, less than one hour and greater than one hour. Typically, the latter case has a failure rate approximately 15 times lower.) To obtain the FTS UR baselines, the FTR rate for less than one hour was multiplied by one hour of operation. The result was then added to the FTS probability to obtain a FTS probability that incorporates FTR within the first hour.

3 Evaluation of Recommended UA Baselines

The MSPI proposes to define train UA baselines by dividing UA into planned and unplanned outage contributions. The unplanned contribution is an industry average value (1999 – 2001) that varies by system and train type. However, because of concerns that industry average values for planned outage contributions may not be appropriate for specific plants, the planned outage contribution is defined to be plant specific, rather than industry average. These planned outage baselines are obtained from plant-specific outage data for 1999 – 2001.

Resulting MSPI UA baselines (averages of the plant- and train-specific baselines) are compared with ROP averages (planned and unplanned outages only) for the entire industry in Table 2. The MSPI mean values were obtained from the 20 pilot plants, while the ROP data come from the entire industry, 103 plants. Again, the MSPI UA baselines, at least in terms of the overall average values, agree with available comparison data.

Also presented in Table 2 are the high and low baselines from the pilot plants. For some of the system train types, there is a large variation between the low and high values.

System	Train Type	MSPI UA Baselines (1999 – 2001)			ROP (1999 – 2001)
		Mean	Low	High	Mean
EAC	EDG	1.3E-2	3.9E-3	2.4E-2	9.4E-3
HPI	MDP	5.8E-3	1.0E-3	1.2E-2	5.2E-3
HPCI	TDP	1.0E-2	7.7E-3	1.5E-2	1.0E-2
AFW	MDP	4.8E-3	2.2E-3	9.1E-3	5.1E-3
	TDP	4.9E-3	1.0E-3	7.5E-3	5.1E-3
	DDP	8.4E-3	8.4E-3	8.4E-3	5.1E-3
RCIC	TDP	1.2E-2	9.7E-3	1.7E-2	1.2E-2
RHR (BWR)	MDP	6.2E-3	3.3E-3	1.2E-2	7.6E-3
RHR (PWR)	MDP	6.0E-3	9.0E-4	2.3E-2	5.8E-3
SWS	MDP	2.0E-2	1.4E-3	7.9E-2	No data
CCW	MDP	8.2E-3	3.0E-4	2.4E-2	No data

Acronyms: AFW (auxiliary feedwater system), BWR (boiling water reactor), CCW (component cooling water), DDP (diesel-driven pump), EAC (emergency AC power system), EDG (emergency diesel generator), HPCI (high-pressure coolant injection), HPI (high-pressure injection), MDP (motor-driven pump), PWR (pressurized water reactor), RCIC (reactor core isolation cooling), SWS (service water system), TDP (turbine-driven pump)
Notes: The ROP data do not distinguish between train types for AFW.

Table 2. Comparison of MSPI train UA baselines with ROP values.

Two issues related to the proposed train UA baselines were evaluated: does plant-specific planned UA vary sufficiently to justify using plant-specific baselines rather than industry-average baselines, and should planned UA data for similar trains within a system be pooled? Both issues were evaluated by examining the planned UA baseline data and follow-on performance data submitted by 20 plants during the MSPI pilot program. Results indicate that planned UA baselines do vary significantly between plants (as shown in Table 2), supporting the MSPI recommendation for using plant-specific baselines for planned UA. However, follow-on UA performance data indicate that the MSPI recommendation to use train-specific UA baselines for systems with similar trains is probably not appropriate. (Differences in baseline values often were not justified based on follow-on performance data from these similar trains.)

4 Summary

The comparisons presented in this paper indicate that recommended UR and UA baselines for the MSPI program are appropriate. These baselines represent component and train performance over the period 1999 – 2001. For both UR and UA, comparisons with other sources indicated good agreement.

5 References

1. Regulatory assessment performance indicator guideline (section 2.2, “mitigating system performance index” and appendix F, “methodologies for computing the unavailability index, the unreliability index, and determining performance index validity”). NEI 99-02 (draft report). Nuclear Energy Institute, 2002.
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